THE ARIZONA WATERSHED PROGRAM
IN REVIEW

Proceedings

6th Annual

WATERSHED SYMPOSIUM

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ARIZONA WATER RESOURCES COMMITTEE

AND

WATERSHED MANAGEMENT DIVISION
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ACKNOWLEDGEMENTS

Including this year's participants in the Sixth Annual Watershed Symposium, almost one hundred authors have contributed to the original watershed study of 1956 and the five preceding symposia. About 40% of these contributors have come from Federal agencies, 30% from State agencies and 30% from private organizations. Contributors have represented a wide variety of specialists, including: hydrologists, foresters, range conservationists, soils men, geologists, engineers, meteorologists, ecologists, fish and wild life specialists, economists, administrators and business executives. So, to the participants in this year's symposium, we again express our gratitude for adding their valuable contributions to the ever growing knowledge of watershed management and its complex relationships.

We are indebted this year to the Salt River Project officers and employees for having made available to us the attractive facilities of the Employees' Recreation Association Club House.

Working behind the scenes on art work, invitations, printed programs, registration and final publications of these proceedings, we acknowledge the efforts of our department personnel: Margueritte Smith, Muriel Bates, Gordon Brown, Barbara Burg, Erma Moseley, Bealuh Ritsema, Lillian Schilling, Linda Duke, Margaret Hunt, Gertrude Dotson and Yvonne Argenziano.

O. M. LASSEN, Commissioner
State Land Department
and
JOSEPH F. ARNOLD, Director
Watershed Management Division

GREETINGS

On behalf of the Arizona Water Resources Committee and the Arizona State Land Department, your co-hosts, I extend a warm welcome to all of you, especially to those who have come great distances to attend this, our Sixth Annual Watershed Symposium.

After listening to what we hope will be an unusually interesting program, we think you will agree the art and science of watershed management in our state has made great strides during the past six years.

It is with the thought of bringing you up to date with what has been accomplished that we have chosen this year's theme for the symposium: "The Arizona Watershed Program in Review".

KEL M. FOX
Program Chairman

Welcome

PAUL J. FANNIN,
Governor State Of Arizona

I am pleased once again to welcome those who have come from outside Arizona to attend this Watershed Symposium, and to compliment the Arizona people who each year make this meeting an important contribution to the growing mass of information about watershed management.

One of the most significant things about this Arizona Watershed Program is that it has been inspired and pushed forward since its beginning in 1956 by a group of citizens in Arizona whose aim is to learn basic facts about the ways in which watershed lands serve the public, and to promote the application of these facts to the practical management of such lands. I congratulate the Arizona Water Resources Committee for its unselfish dedication to that purpose.

The success of the Committee's program may be measured by the interest, cooperation and actual work being done by the many government and private agencies which have land and water research and management responsibilities in Arizona. Without the inspiration and assistance offered by the Arizona Water Resources Committee I feel sure the search for knowledge and understanding in these matters would not have advanced as rapidly as it has.

The Arizona Citizens' Committee was also largely responsible for the establishment of a Watershed Management Division in the State Land Department, and that Division is a key factor in the continuing cooperation and coordination between the agencies involved in the Watershed Program.

One of the most encouraging things going on right now in Arizona is the growth of widespread public interest in the full and orderly development of the State's productive resources, which include water, timber, grazing, minerals and that hard-to-classify, but very important factor — wildlife and recreation.

I will not attempt to list those resources in the order of their importance, except in the case of water, which everyone recognizes must have a top priority in State Development planning. An adequate water supply is essential — a first requirement — for the beneficial use and management of all our other resources.

For many years knowledge and interest in water was largely limited to a relatively small group of recognized experts representing specialized groups of water users. Agricultural and mining interests were the most effective developers of water resources for many years, because they were the most directly concerned, and because their operations demanded large quantities of dependable water.

But with the great and rapid growth of population and industry in the State in the last few years, and the inevitable competition for the limited water supply, other users of water have been awakened to the problems of supply and distribution. Cities and industry, lumbermen and sportsmen, cattlemen and politicians have joined the farmers and miners in being concerned with the development of our water resources.

This is all to the good. Special interests and the public must be aware of their basic need, and the problems relating to it, before anything much can be done to solve the problems.

Important as it is to all of us in Arizona, we will not have completely solved our water problems when we bring Colorado River water into the heart of our State. Arizona will still be a water-deficient state when it has put to use every drop of its share of the Colorado River. When we have accomplished that, as we must, we will then have to depend for additional available water upon an increase in use-efficiency and conservation.

Agriculture — the greater user of water — has accomplished much in the elimination of water waste by lining canals and ditches to prevent loss by seepage, in the control of water delivery to more precisely match demand, and in the scientific application of water to meet the needs of specific crops. Agricultural research and management will continue to improve the efficiency of water use on farms.

The major mining companies have actually reduced the amount of water required per ton of processed ores through new processes and intensified re-use of water.

Cattlemen — always relatively small users of water — have increased their water-use efficiency by making it available in areas that could not be grazed before. This must be considered an increase in the productive value of their use of water. The clearing of worthless junipers from thousands of acres of range lands is a conservation of water because it promotes the production of valuable grass.

Perhaps the weakest link of all in this picture of water conservation — and one which is bound to become increasingly important in the years ahead — is the use of water by people who live in our cities. At least half of the water put into municipal water delivery systems is now lost in the sense that it is used to conduct waste products away from the city users. This loss of water can be eliminated by practical methods of water treatment and beneficial re-use. But before that becomes possible the public must be educated to the idea and willing to invest public money in the necessary treatment facilities.

The Arizona Watershed Program, as you know, fits perfectly into this picture of water conservation as a source of more water available to all of its beneficial uses.

The aim of the program, as I understand it, is to make the water that falls on our watershed lands produce more commercial timber per acre — not more trees to compete unsuccessfully with each other for limited soil moisture. The program is aimed at producing grass for grazing and soil protection where that appears to be the best use of the land and water resource. It is aimed at reducing loss of water by transpiration from worthless vegetation where other types of vegetation can be safely and practically substituted. It is aimed at improving wildlife habitat.

It is aimed at producing more water runoff where that can be accomplished safely. In short, it is an attempt to increase the efficiency of watershed lands and make multiple use of such lands something real and meaningful to the public, rather than a theory to be talked about at an academic level.

The cord that binds the whole program together is Arizona's need for good dependable water to keep all the facets of our growing economy strong and healthy.

I expect this sixth annual Arizona Watershed Symposium to do what the other five have done; that is, cast more light upon, and increase our knowledge of, the ways in which we can — through enlightened management — make more water available in Arizona for future generations of our people.

If our children and theirs are to live and prosper here, and if Arizona is to continue to occupy its position of importance in the Nation, we must develop and conserve every drop of water that comes our way. To this end I know you people here today are dedicated, and on behalf of the citizens of Arizona I express appreciation for the work you are doing.

The Arizona Watershed Program In Review

By C. C. COOPER, JR.,
President, Arizona Water Resources Committee

I realize that I am addressing an audience made up largely of old friends of the Arizona Watershed Program. Therefore, I am going to avoid insofar as possible, giving you a blow by blow description of the Program's development and progress. Rather I will mention only what I think are the most interesting highlights of our past and our present and then make a few observations about the future.

I might say at the outset that if there have been any significant changes from the original concept of the Arizona Watershed Program, they would have to lie only in the revelation that beside water yields there were tremendous gains to be made in all other aspects because of good management for water. Insofar as the development of the Program is concerned it has followed closely along the lines of its original plan. The plan was this; first find out what the conditions were that could be responsible for the continuing drop in water yield, the lowering capacity to support livestock and game animals and the obvious over-population in the stands of mixed conifers, ponderosa pine, juniper and chaparral. Second, was to determine what, in the minds of the experts, could be done to correct these conditions. Third, to test by scientific means the management practices that were recommended by the experts. Fourth to find ways to put the proven methods into full scale application.

Only six years ago the Program was still in its survey stage. A preliminary survey by a gathering of watershed technicians and specialists from all over the United States was sponsored by the University of Arizona, the Salt River Project and the Arizona State Land Department. With the availability of their report the Program passed into its second state of development — that of action. This action came about in the form of the creation of the State Land Department's new Watershed Management Division and the appointment of a Citizens Group called the Arizona Water Resources Committee. Together they formulated what we refer to to-day as the Arizona Watershed Program.

Then it entered into the research phase — a phase which will continue for years to come though it is now being paralleled by the final phase, the full scale application of proven treatment methods which have already been underway for a year or more in some instances. In effect, while we are learning about what can be done in some fields, we are encouraging the use of those watershed management techniques which have already proven their worth. Yes, we now have the facts which justify large scale application of several of our original concepts. But we also know that ecological relationships on a watershed are extremely complex and that continued research is an absolute must if the Arizona Watershed Program is to continue on firm ground.

The necessary years of pretreatment calibration for water yield information and the subsequent years of stream-flow measurement after treatment demand that we be patient and avoid premature conclusions about water yields from certain of our pilot projects. However, the other benefits such as timber stand improvement, forage development, wildfire fuel reduction and improved recreational conditions bring us to the realization that large scale application of such practices as ponderosa pine thinning, clear cutting patches in mixed conifers, juniper invasion control and chaparral management for better livestock forage and game habitat can now be considered as proven watershed management tools.

I don't want to create the impression that as yet we know nothing about water yield from treated areas. Actually, preliminary figures vary from encouraging to downright dramatic but we realize that much analysis of the data at hand remains before we can make absolute claims of fact concerning water yields from *all* of our projects. Any publicity to the contrary, we want it known that we are not now and never have been advocating *premature* application of full scale treatment practices. Nor do we sanction *premature* claims of results which are not scientifically proven.

And while I am on the subject of what we are not doing, let me state that we will never advocate watershed management practices which do not give *full* consideration to *all* of the multiple-use values.

Enough of the negative — returning to the positive. Just how far along is our Program today? By "our", I refer to an impressive list of cooperating agencies, business organizations, civic minded citizens and associations. I want to read you this list because I am sure you will agree on hearing it that the Arizona Watershed Program and all it encompasses is not only unique but probably the most significant effort of its kind to-day. Here they are:

The United States Forest Service
The United States Geological Survey
Agricultural Research Service
The Bureau of Reclamation
Arizona State Game and Fish Dept.
The University of Arizona
Salt River Project
The Livestock Industry
The Mining Industry
The Arizona Bankers Assoc.
The Arizona Development Board
The Boy Scouts of America
The Bureau of Indian Affairs
The White River Apaches
The Soil Conservation Service
The Army Corps of Engineers

Arizona State College at Flagstaff
Arizona State University
The Arizona Assoc. of Irrig. Districts
The Chemical Industry
The Timber Industry
The Heavy Equipment Industry
Arizona Public Service

and, of course, your hosts

The Arizona Water Resources Committee
and
The Watershed Management Division
of the State Land Dept.

I am sure you can see that the word "our" refers to hundreds of individuals who are, in one form or another, contributing time, talent and fortune toward our goal of good resource management, specifically toward the primary purpose of intensive watershed management in its larger sense. Unbelievable progress has been made. And why shouldn't this be, with the cooperative effort of so many.

Cooperation and coordination with their corrolary benefits of communication and understanding are the principal keys to *this* Program's success to date.

Referring again to our original plan, let me repeat that we are to-day in the phase of combining continued research and broad scale application of proven methods. By way of giving you an indicator of just how large this Program has grown to be, I would mention that we anticipate that next fiscal year there will be over a million and a half dollars allocated to the specific purposes of furthering our program's recommendations. This is a sizeable expenditure by anybody's standards and I am sure there is no doubt in anyone's mind but what we are getting our money's worth out of it.

Lest there be some confusion in your mind, the Arizona Water Resources Committee has been able to perform its functions on a small annual budget which has been met every year by voluntary contributions. This year, however, the importance of creating a more versatile and up-to-date media for telling our watershed story became a major project of the Committee. Consequently we gathered up our courage and contracted to make a 16mm color, sound, motion picture. This movie will depict the application of the program's recommendations on the Cibecue Watershed of the White River Apaches. This was a very ambitious undertaking we know, especially in view of its cost. We have had some very generous contributions thus far and we are optimistic about being able to raise all of the money needed. But if any of you have any suggestions to offer toward this end we will listen most receptively.

As I mentioned in the beginning, I do not want to burden you with detailed explanations of the status of all of our projects; but I am going to tell you now about some results from a few of them that I am sure will interest you.

The first one refers to the Program's recommendation of clear cutting mixed conifer stands in patches. In the Sierra Ancha Experimental Forest they precalibrated and then clear cut on an 80 acre area of mixed conifer timber in a 248 acre watershed. They then measured the results over a period of years and found that increases in run-off varied from a 10 acre-foot increase in yield during a subnormal rainfall year to a 40 acre-foot increase during an above normal year. Other clear cutting test plots are in progress on the Apache National Forest. The Forest Service is sufficiently impressed by this and other related benefits that they feel justified in planning to clear cut several thousand acres on a commercial basis. Game managers and stockmen are most enthusiastic in their anticipation of the benefits to be derived from this opening up of the forest.

Another case of important increases in water yield occurred at Cottonwood Wash in Mohave County. There, the elimination of 22 acres of cottonwood trees along the stream bed resulted in an increased water yield of 1.9 acre feet for each acre so treated, according to the United States Geological Survey Report. This amounts to enough water for 187 people for one year at the rate our folks use water in the Phoenix area.

A large scale application of stream bed vegetation modification is being carried out by the Apaches on their Cibecue drainage. Gains in water yield from this 500 acre area will only have to approximate those realized on Cottonwood Wash to be of tremendous benefit to the Indians and the down-stream users.

Results in terms of gains in water yield on projects involving the Arizona Watershed Program's other recommendations, such as ponderosa pine thinning, juniper removal and chaparral management are not yet at the stage where we wish to interpret them conclusively. However, it was accidentally learned, as the result of a wild fire on the 3-Bar project, that chaparral removed in this manner produced a seven-fold increase in water yield. As expected, however, soil erosion is also a serious result and wild fire is certainly not to be considered a management tool. There is reason to believe, though, that fire can be employed as a management tool in chaparral as is being demonstrated by controlled burning tests being carried out by the Forest Service Research. If their studies continue to be as encouraging as their early efforts would indicate, then this method of controlling chaparral growth may not only be of tremendous benefit to forage development and water but would likely lead to a practical way to minimize the wild fire potential in this zone. This development in our Program should be of considerable interest to our California neighbors, not to mention their insurance companies.

Of course water has been our program's prime motivator and understandably so. But, as I mentioned earlier, we now know that related benefits to other multiple-use values are in *themselves* turning out to be just as significant to the future production of our watersheds. For example, relative to our recommendation of juniper invasion control, a 10,000 acre juniper infested area that was cleaned up and reseeded to grass jumped from a cattle capacity of 93 head for five months of grazing to an anticipated 1500 head capacity — a potential 16 fold increase. The Arizona Watershed Program does not take credit for initiating the practice of juniper eradication. Range managers have been resorting to juniper eradication to reclaim their grass lands for many years but, under our program, this practice is also being studied for its relationship to water yield.

There are still other related benefits to our State's economy because of the successful development of the Arizona Watershed Program. For instance, consider the opportunities opened up to the suppliers of equipment and materials used in the treatment methods. Also, because of the proven value of clear cutting and thinning timber stands, a favorable climate was created for the establishment of the Southwest Forest Industries' pulp mill near Show Low, a new industry for Arizona. Further, the program has encouraged and assisted in the expansion of scientific and educational facilities in our schools of higher learning. You will hear more about this later in the day.

Now what do we see in the future? This much we know, the demand for more intensive watershed and wild land management is becoming stronger every year. This has to reflect itself in the allocation of more manpower and money by the land management agencies toward the purposes which complement our program. These demands stem to a large degree from the pressures and impacts of an expanding population and the attendant need for intensive multiple-use management. At the *outset* of our program's development there were many who were forecasting this condition but I wonder how many of us fully realized at that time just how soon this situation would come about. In these past six years we have seen a Senate committee complete an exhaustive evaluation of our nation's water supply and found it wanting. Land management agencies have been asked to inventory the present capacities and projected capabilities of *their* lands. A nation-wide survey of future recreational needs has been made.

Looked at from the viewpoint of the professional watershed specialist, these circumstances are certainly putting a premium upon his services. The research man now knows that his findings are needed for *immediate* use. The technician knows that his knowledge and skill will make a more significant contribution than ever before. Administrative and management personnel of public land agencies realize that they must intensify their efforts and must seek the cooperation of land users in order to achieve their goal. By land users I mean the grazing permittee, the timberman, the sportsman, etc. These people too *must* recognize their own responsibility and that good watershed management will depend upon their efforts just as much as it does on the professionals.

This brings me to what I consider to be one of the most difficult problems coming up in watershed management. I would describe it as an inevitable conflict of interest under multiple-use. It would be far easier if each multiple-use value could be developed with equal emphasis, but this is not realistic. Choices do have to be made. Decisions as to the best use of a given area have to be arrived at and they will need to be based on many factors such as geographical location, terrain, climatic conditions, soil conditions, proximity to population centers, etc. It is these decisions, good or bad, that will bring out criticism from conflicting interests. Not that they will necessarily be justified, rather they will arise primarily from a lack of understanding and appreciation of the larger values. Consequently, expanded programs for public education and public relations are as important a tool of management as any we use.

The Arizona Watershed Program has been fortunate in this connection. At the outset, when little was publicly known about our recommendations or the methods to be employed, there was some reaction on the part of a few who had the mistaken belief that vegetative modification meant the destruction of other watershed values for the sake of water alone. This mistaken concept, insofar as it was publicly expressed by the uninformed, did not noticeably retard the program. But it did impress us with the importance of getting the true story told as soon as possible.

In addition, the constant efforts of the Arizona Water Resources Committee to bring together all of the interests concerned, to encourage them to participate in the development of the program and to take part in its execution, minimized the possibility of interagency conflicts. This effort of stimulating action and coordinating all of the research projects has been one of the most valuable contributions the Committee has made.

The vast majority of the land in our western states is in state and federal ownership. Consequently, ways must be found to encourage tenant land user participation in watershed improvement practices for their own benefit. If it can be shown to the stockman or the sportsman that it is to their benefit to develop more forage by clear cutting, thinning pine, removing juniper and controlling chaparral, then it is time to expect their participation. But, before the public land user becomes very interested in putting his money into public land improvement, he is going to need more assurance of tenure, longer term amorization of the cost relative to his lease or permit and more cooperative funds from the management agencies.

These matters are being discussed. We hear them in meetings of Advisory Boards and Councils, and this leads me to the belief that the way is opening for greater participation because of better communication and understanding. We also note that there seem to be more public hearings relative to public land management. I hope this trend will continue and that the non-professional citizen will take full advantage of these opportunities to participate in the planning for our future. Local conditions are best presented by local people. If we leave everything to be worked out at government level, it is not likely that our best interests will always be served.

Before I conclude, I want to indulge an old theme of mine. It is what I think is the logical answer to the complaint that too much public money is being diverted into agricultural type improvements. I cannot quarrel with the argument when it refers to subsidizing inefficient production. But I do resent the confusion with money spent for resource management.

Soil and water are our only resources that *can* be improved with use. Insofar as conditions exist which clearly indicate that this resource needs developing or managing or recovering, then funds directed to this purpose develop our national wealth, our capital assets, renewable assets if you will. Many of the world's greatest civilizations succumbed because they permitted their agricultural resources to become exhausted.

Now don't misunderstand me. I do not mean by this that we should "over protect" our lands. This is stagnation —or reversion to unmanaged wilderness. The day is long past when we can wait for natural elements to restore or to correct imbalance.

We have to know how to use this resource and maintain a sustained yield forever. But it takes careful management and some long term investment to do it.

In conclusion let me say again that we are proud of our local accomplishments for better watershed management here in Arizona. We are sincerely appreciative of the cooperation we have received from all of the management and research agencies. We are encouraged by the inquiries we are receiving from other states and other parts of the world. It is my sincere hope that by the time my generation must turn the task of watershed management over to our young people, that we can do so feeling that we have been good managers and not neglectful in the development of this resource.

I thank you for your kind attention.

A Look At Watershed Management Progress In Arizona

HERBERT C. FLETCHER
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It is a pleasure for me to be with you today. I have some fond memories of experiences I had while I lived in this area. I am somewhat apprehensive to approach this subject because many of you have been much more closely associated with Arizona watershed problems longer than I. It only seems like a few months ago that Ray Price, Jake West, Tex Norman, Bill Pickerell and I sat down to see how the Salt River people could become more interested in the research work the Forest Service was conducting at Sierra Ancha. It was several years after this that through the leadership of Rod McMullan and the Board of Directors a timber harvesting program at Sierra Ancha was undertaken to determine some of the effect different watershed management practices have on water yields. Now you have a variety of projects in different vegetation zones designed to study these conditions, and several action programs have been initiated by the Forest Service and Indian Service to increase usable water supplies and improve the forage for livestock.

Watershed management studies started back as far as 1910 on a modest basis. During 1932 the Forest Service set aside the Sierra Ancha Experimental Forest to study soil stabilization, hydrology, and sediment reduction under arid conditions. These research results have provided some of the basic information now being used to develop watershed management plans. Early in 1956 the State Land Department, the Water Users Association and the University of Arizona published the Barr report which stimulated much interest in the water problems and eventually led to the establishment of the Watershed Management Division of the State Land Department. Needless to say, the recommendations of the study group were not completely acceptable to every one. The job was a large one. The major task remained to pull a program out of the mass of data accumulated upon which Arizona could proceed with some plan to achieve the projected goals. You have made some notable progress toward some of these goals but much remains to be done. I would like to review some of the progress you have made and call to your attention some of the places where I feel greater progress will be made to meet the growing demands for water.

It is needless for me to remind you people that water is your most important resource, basic to everything else. With an adequate supply of water, your future is limited only by your imagination and energy. Without it, no matter what else you may have, there can be no significant progress and no future for the State. Other civilizations have passed out of existence in this arid land, and water could be the limiting factor to your future progress.

In this fabulous day and age when man is not content with the conquest of the planet on which he lives, but stands on the threshold of the conquest of space; when he has brought under his direction and control forces beyond the dreams of his forebears and actually threatens to destroy civilization; when rapid communications and travel have brought the farthest corners of the earth into close proximity and each day brings a new synthetic fabric or a more efficient and new machine more ingenious than the last — in this day of miracles and wonders, the importance of water, its control and its use is not one bit less important than it was when the foot of man first trod the earth. We have machines that transport us and work for us with far greater speed and efficiency than the old beast of burden, but we don't have a mechanical substitute for water.

We know how to produce beautiful crops made bigger and tastier by artificial fertilizers, synthetic foodstuffs of surprising palatability and nutritive quality, we even have laboratory produced vitamins, but in 10,000 years, man has not distilled or synthesized or otherwise developed a single drop of any laboratory substance that can do the work of water. In fact, the advance of civilization has brought a steadily increasing demand for water, not merely because of our increase in population numbers but also because of our per capita requirement for water has increased unbelievably.

It is hazardous to describe a trend that cannot be expressed in quantitative terms because the results tend to reflect the personal bias of the individual. On the other hand a quantitative analysis of trends in watershed development would not reveal the significant changes that are taking place in our approach to watershed problems and management. I accepted this assignment with a clear recognition that probably no two individuals would interpret what is happening in the watershed management field in exactly the same way. Although many of you may disagree with some of my viewpoints or conclusions, my efforts will be adequately rewarded if I succeed in provoking thought on the problems confronting you in the development of sound watershed management concepts and practices.

If we look back from our vantage point in 1962, it seems to me that the end of World War II marks a substantial change in both the accepted concepts and the approaches to the watershed problems. First I would like to examine some of the changes that have been occurring in our concepts and second I would like to call to your attention some of the trends that affect the programs here in the Southwest.

Consider the population increases that have taken place here in the State. The percentage increase is far above the national average. Arizona's population has more than doubled in the last thirteen years. It is expected to double again in fifteen to twenty years. This growth is expected to continue at its present or increased rate if the water is available. Even with the remaining surplus water that is expected from the Colorado River, the State will have to husband all of its supplies to meet its expected growth. Clearly this is an area in which major decisions must be made to integrate a deficient water supply to an increasing population and its accompanying demands for water. The time is fast approaching when water requirements will be met largely by wise water management which can only be supplied from local watershed sources. Recognizing also that some break-throughs will be made in desalinization of brackish and sea water to replace fresh water in areas close to the source of supply, we will still be hard pressed for potable water.

Here in Arizona the largest consumptive use of water has been for irrigation. It was one of the earliest major uses and was the backbone of this great valley in point of time. Most of the early development has been associated with agriculture developments and pursuits. This policy has had great benefits. It has been the base on which this State has grown to the stature it now has. During the last 10 to 15 years this domination has gradually given way to other interests. Other interests are demanding more and more attention. Municipal and industrial demands are increasing. In most cases these demands can only be met by a change in land use. Another demand that is attracting considerable attention is water for recreational use. This can be in many forms and in many cases is conflicting with other uses.

The pump has had its part also in changing the pattern of water demands and use in this area. In some areas of the State pumping has not had the influence it has had in others. In some areas it has had an immediate reaction upon the availability of the water from surface sources. It must also be credited with the elimination of considerable amounts of nonbeneficial consumptive use of water, thus making it available as salvage water.

Throughout the State demands for water are changing in character as the population increases. The way water is being made available is changing. Pumping systems are becoming increasingly important. Water salvage systems like that recently approved by Buckeye will become increasingly important. In addition there are many decisions with respect to policy and administration which have to be made by a citizenry which at best is poorly informed with respect to the question of water use.

It is unfortunate that many of the people who must participate in the decisions on the shortage of water are new comers to arid conditions and have no background or understanding of the hydrology of arid lands. A large number of these people bring to the State a knowledge of hydrology they obtained from the more humid sections or the colder areas, and they attempt to apply this knowledge to arid conditions. Unless some educational program is effectively carried to the man in the street, the values of watershed management and its importance will not receive the support they must have to insure an effective program. New arid land concepts must permeate his thinking.

What can be expected to be done to establish reasonable and effective policies of water use? To me the answer is quite clear. Neither the amount of water nor its physical availability will be changed by legislative or judicial action. The amount of water available for use can be modified only by effective management of your water systems. I am thinking not only of the watershed lands but the rivers and reservoirs of all types. You have done a great deal to conserve your water in the reservoirs or the laterals, but I am sure Rod McMullan, or anyone else familiar with the problem, would be one of the first to admit that there is much more that could be done to conserve the supplies. I would also have to include underground supplies. Little progress can be expected as long as so little is known of the details of the hydrology of the State.

Why are investigational studies and research inadequate to provide a knowledge which would be the basis for the outlook on water? There are several reasons for this. One is the complexity of the area. One only has to look at the sources of water in this State to realize the inadequacy of hydrologic information. Lowel Rich and I tried at one time to group the Southwest into three major water and sediment yielding areas based on the evapo-transpiration rate. (1) Each area had its own hydrologic characteristics which in turn had their own variations in the combination of water source and use. The climate and therefore the hydrologic response of different sides of a hill can be distinctly different. There is a wide variation in the way in which water occurs. More knowledge of the relation of kind, form and arrangement of vegetation cover to water yield is urgently needed.

At the lower elevations the major objective of watershed management is to improve soil stabilization and reduce sedimentation. This may necessitate mechanical structures and improvement of vegetation or both. If on-site use of water is increased by developing or improving usable vegetation, surface runoff and the attendant soil movement may be reduced. A secondary beneficial watershed use of the grass may also be increased.

In the intermediate water yielding zone (elevations from 5 to 6 thousand feet) the coordination of watershed management practices with range, timber, recreation and other uses must be worked out to determine how these other uses affect water yields and sedimentation. Hydrologic research must be increased to provide the answers to problems of wide variance which are relatively expensive but more importantly are time-consuming to conduct.

Water transport and the simple measurements of water levels to guide the use of ground water are an exercise in futility in this and the lower zone. Each aquifer must be evaluated in terms of its area. Amount of water available, the recharge potentials and methods of recharge, effects of different rates of withdrawal are only a few of the factors that will need intensive management as demands increase.

At the higher elevations (above 6,000 feet elevation) which provide the largest amount of the now usable water, watershed management must conduct research to find ways to manage vegetation, both grass and timber and snow pack to obtain the highest possible yields of water. It is in this area the potential of improving water yields is the greatest because of the higher precipitation rates and the lower evaporation and transpiration levels. Additional studies are urgently needed on the accumulation, melt and evaporation of snow under different vegetation conditions, topography, soil and climate. These are only a few of the studies that are needed to improve the watershed management data so that more effective management practices can be applied.

One cannot rationalize the use of surface water in the State without evaluating the effect of a diversion or the storage of water at a given point on another point in the same stream system. These diversions or storages may be natural or artificial. Included in this is the non-beneficial use of water by phreatophytes. The amount of water by this diversion is not certain nor is it known how it may be subject to management. Some significant progress has been made in this direction, however.

The effect of large numbers of stock tanks cannot be established precisely, so there has been contention between the users of the upper watershed and the lower users. This subject was a major contention between the San Carlos water users and the upper users during the 40's. The problem still cannot be answered today. I cite this to show only the slow progress that is being made on some of the obvious problems. The fact that many of the critical questions cannot be answered today indicates that present systems for collection of data and more particularly for the analysis of new and old data do not meet present and fore-seeable future requirements which will permit better watershed practices to be applied.

Progress will be made I feel only if those charged with administration of water conclude that an understanding of the hydrologic systems are fundamental to the discharge of their responsibilities. They must be so convinced of such requirements that they can, in turn, convince the legislators who must appropriate the money needed to undertake the studies and measurements.

The Arizona Watershed Program has served a very useful purpose in guiding the policies so that enlightened people are nominated who understand water and watershed problems. They can also serve as a disseminating point for getting data into use by all interests. The Forest Service, Soil Conservation Service, Bureau of Indian Affairs, Bureau of Reclamation, Bureau of Land Management, Geological Survey and Agricultural Research Service all make fundamental investigations of hydrologic and watershed conditions affecting their programs. With only a limited audience, which many programs have, considerable data never comes to the attention of the public unless there is some State agency to collect and correlate the data.

Sound watershed management objectives formulated to the needs of the State provide an organizational means for stimulating and supporting those kinds of research which are essential to improve your possibilities to cope with your ever mounting water problems. The basic purpose of a good research program is to improve the understanding of water in the context of its environment in and on the earth. This purpose requires a great variety of specific activities which also have more immediate purposes. These activities and purposes, however, sometimes obscure the over-all goals. The data in themselves have many uses, but they are not in themselves accurate assessments of water resources nor do compilations of data by themselves explain how the hydrologic system functions. Symposiums such as this provide a focus and a source of emphasis and guidance for basic research programs. Problems in the basic research area are unanswered questions, but watershed management problems are problems which must be supported by the best research available upon which some action must be taken toward solution whether or not it is the final word in scientific data gathering.

Here in Arizona you have been conscious of your many water problems and have taken steps to bring these problems to the attention of your research people and State legislators as well as supporting your Federal congressional representatives in obtaining facilities and programs to work on arid land problems. Senator Carl Hayden has for many years been extremely instrumental in bringing to Arizona such programs as the phreatophyte investigations of the Forest Service, the Southwest Water Conservation Laboratory here in Tempe, the Watershed Management Outdoor Laboratory in Tucson of the Agriculture Research Service. These are only a few examples where stepped up programs have come your way because of the State and local interests in watershed management.

These physical facilities which I have briefly called to your attention represent spectacular possibilities of great interest, and the potential developments that can be visioned will doubtless have a major impact on the water supplies of this State and other States for a long time. However, I feel quite certain that the greatest impact in the future will be in doing better, the continuing everyday tasks of better planning and engineering of your ordinary water supplies and in the improved efficiency of their use. These tasks are the unglamorous and tend to go unnoticed. It seems to me they need a share of our better thinking and more attention than they are now getting. Some of these ordinary tasks which need to have ordinary attention are:

a. Describing and undertaking the water supply of the State.
b. Improving the nature of the supply.
c. Use of ground water.
d. Quality control.

These are only a few of the tasks I would like to have you think of for a few moments in relation to what the future watershed program should be in Arizona and the Southwest.

A. Describing and understanding the water supply of the State. It is axiomatic that any water supply development should be founded on an understanding of the pertinent water supply. Improved water supply information is therefore a matter that needs serious attention. Most water supply information is based largely on relatively limited stream gaging, a few sediment and pollution studies, some snow surveys and related meterological observations, mostly through indirect interest. We need more field measurements. We will probably never have enough, but I don't feel that just expanding our gaging stations is enough. We need a breakthrough in developing automatic field censor units, mass produced and inexpensive to sense runnoff, temperature, snow cover, precipitation, evaporation, wind movement, etc. Data should be telemetered, automatically recorded and analyzed by machines. We must develop methods for evaluating the water supplies of unmeasured watersheds. We need to know not only total annual runoff but the nature of its occurrence. Its distribution and its quality must be described both in time and space. The major portion of our data are only statistical records of the past. They do not yield the future, only probable expectations. It seems to me we need to take a good hard look at our watershed management program and overhaul it to meet this jet age. It needs a better basis in science, it needs modern techniques and it needs broad, objective, realistic planning and programming.

B. The second task that is before us is improving the nature of the supply. Aside from increasing the quantitative amount of the basic supply, there is still much that can be done to improve its physical nature. Man's most profound physical affect on the water supply probably arises from the provision of reservoir storage. Industries and population could not exist in this arid valley if it were not for our great engineering works of storage and conveyance of water. We have made great strides in this field since Roosevelt Dam was constructed. These advances have not only come in research but in the entire technology involved. We need much more. In the Southwest in many cases we pay too high a price in evaporation from our reservoir storage. Evaporation from free water surfaces, around 7 to 8 acre feet from Roosevelt Lake, is therefore of paramount interest to all. Some work I understand is under way here at the Tempe Conservation Laboratory as well as elsewhere, but we are a long way from having the problem under control. The conveyance or transportation of our water supplies is also of major importance. We have greatly improved our conveyance devices, including pumps, but there is much to be done. Transportation costs are too high and open channels are frequently subject to excessive seepage.

C. The third important area is our ground water supplies. This is essentially a storage program. It may be short or long term. Annual or periodic withdrawal may be limited to annual or periodic recharge, or on the other hand waters accumulated over extremely long periods may simply be mined and the resource exhausted. While some good work is being done in this field, we do not have reliable information on how to manage most of our ground water basins. Public policy in regard to ground water utilization needs very careful, long-range study in considerable detail.

Proper management of the ground water resource could go a long way toward eliminating transpiration by uneconomic vegetation which would also reduce water loss.

Extensive information on the extent of ground water resources, the transmissibility of aquifers and their recharge potential is continually in short supply. Here also new and improved techniques for obtaining, compiling, and analyzing large masses of data would be helpful. Well technology has made great strides in recent years, however there seems to be much room for improvement.

We also need to be able to extract the water from aquifers of low transmissibility. The economic value of devises for this purpose could be of great importance.

D. The fourth important factor where much improvement will need to come is in the area of water quality — pollution, which makes water unacceptable, is a serious threat to many of our supplies. On this point the Select Committee on National Water Resources has this to say: 2)

> "Unless the country is ready to cope with water pollution on a far greater scale than at present, it appears that many streams will become putrescent and our rivers open sewers."

Based on present technology the trmeendous need of water for waste dilution will strongly dominate the future nonconsumptive use load placed on our water supplies and may well encroach heavily on consumptive uses. We need to attack both the waste disposal problem and improve sewage treatment technology head on. This is an area where we need especially bold thinking.

Practice has led us to think of disposal more and more in terms of flushing wastes down the sewer. With a little thought and effort we may come up with some very attractive ideas for waste disposal systems requiring greatly reduced quantities of water.

I expect to see flush toilets and other water wasting facilities used here in Arizona for a long time to come. On the other hand, I question the wisdom of the extravagance in many arid regions of allocating water to most forms of waste disposal with no thought to water saving alternatives. As has been pointed out by the Senate Select Committee, "research and development of new techniques and processes for treatment of wastes are needed in two directions. First, to permit reduction in the costs of the pollution abatement job, and second to develop techniques for dealing with some of the newer and more unusual types of wastes which cannot be handled by existing methods of treatment." 2)

There is also a great need to develop methods of reducing the sediment and other pollutants coming from our watershed lands. Water for domestic use obtained from controlled and properly managed watersheds is being produced with a minimal treatment at a cost of about one dollar per million gallons. By contrast, it costs on an average of about 40 dollars per million gallons to treat contaminated or turbid waters to produce a less desirable product. Protection of the water resource, whether by specific control measures on the streams or by proper management practices on the watersheds, must be recognized as a part of any enterprise using or capable of effecting water.

It is well recognized that basic to proper planning is full knowledge of factors controlling the water resource. Physical conditions of the watersheds control water yields as to amount, timing, and quality; and to a considerable extent the various possibilities for management. Physiographic and climate characteristics as well as land use and conditions are significant factors in areas where water is scarce and land is plentiful. The day may not be too far off in our water short areas when water supplies may need to be considered as the "Master Resource" to which other elements of the economy will be adapted and physically arranged in such a way as to provide the most efficient use of the limited water by society as a unit. This then becomes a public management problem. It may require some kind of public authority and planning based on factual data and economic farsightedness.

These are only a few of the highlights of research needs and other practical needs and how they may affect the future use of water. I have mentioned research for the development of technology and research necessary for better planning and public management. In addition to basic research we must be concerned with the reduction of this information to practice. This is where I think the watershed program of the State can make its greatest contribution. We seem to have gained the idea that only research studies of tangible physical variables is scientific. We discount as unworthy of intellectual investigation the great problems which require a broad but more indirect approach based on creative induction from case histories, or which deal with the less measurable facts of economics, social considerations and politics.

These are just a few of the major elements of watershed planning concerned primarily with the physical relationships of water resources. We have made substantial progress but there is urgent need to accelerate greatly our current rate of progress if we are to meet the spiraling needs for water.

We must rethink on the basis of fundamental principles the various causes of water demand and set about on a much expanded program of research and applied technology to reduce the amount of water required for a given product, activity, or use of water. It is only if we go back to the basic principles we will make significant progress. We must no longer have watershed management and research programs considered as a part of agriculture or industrial production but rather as a natural resource deserving separate and special treatment for its own sake. As long as it is a branch of such headings as agriculture, industry, municipal, recreation or hydropower, we will never have the funds to give adequate study to water as a natural resource and water demand in particular.

1) *Classifying Southwestern Watersheds on the Basis of Water Yields. H. C. Fletcher and L. R. Rich, Journal of Forestry, March 1955, P. 196.*

2) *U. S. Senate Select Committee on National Water Resources Report. Senate Report No. 29, 87 Congress, 1st Session 1961.*

Arizona's Paper Industry As Related To Watershed Management

by EDWARD P. ENDERS
Industrial Director Arizona Development Board

When I was notified, last July, that I was to talk on a subject on which I was definitely not an expert, on a subject that even the experts admit they will not know too much about until after experiments covering a period of X number of years — to be given on a program made up of experts — I decided that I would not attempt to become a forester or a hydrologist in this short period of preparation time. But I would like to say a few words about how the Watershed Program and the paper industry affects the economy of the State of Arizona and the program of the Arizona Development Board.

The Watershed Program in Arizona was initiated in 1956. The Arizona Development Board was created by the State Legislature in 1954. The function of the Watershed Program is to conserve and to obtain the fullest utilization of water for Arizona. The function of the Arizona Development Board is to promote industry and industrial development in Arizona and to promote and encourage tourism, recreation and travel in the State of Arizona.

The paper industry is one of Arizona's largest industries and its largest new industry. It is vitally affected by water. The Arizona image throughout the East and Middle West is one of desert and cactus. Each year the Development Board puts on a display and participates in travel shows in places such as New York, Milwaukee, Minneapolis, Dallas, Los Angeles, and San Francisco. When we show our publications, such as "Water Sports in Arizona" and "Arizona Has Trees", most people are dumbfounded. They have the same reaction as they would had we told them that the largest industry in Detroit, Michigan, was the manufacture of buggy whips.

Tourism has increased in Arizona from $60,000,000 in 1946 to $320,000,000 in 1961. By 1972 we expect the figure to reach $1 billion. I can't give you exact proportionate figures but I believe that the largest increase in our tourist and recreation participation is in the areas affected by water and water sports. Water skiing, boating, and fishing are becoming more and more prevalent in Arizona, as in the rest of the country, with the increased leisure time of retired people and production workers.

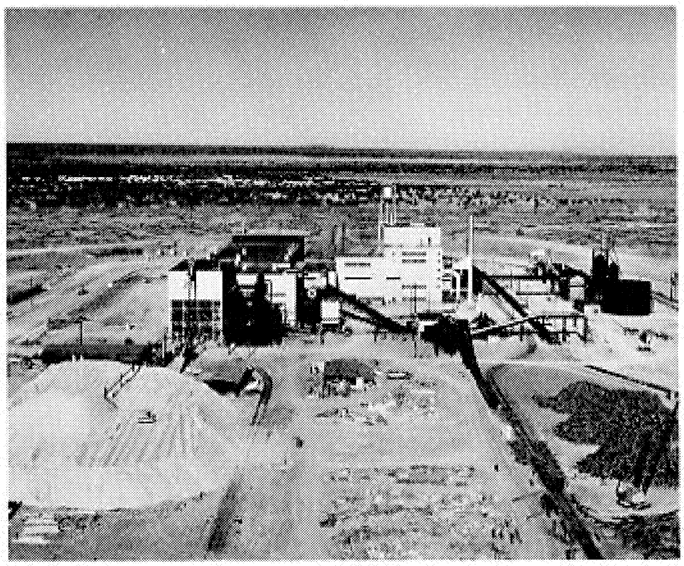
In making a cursory analysis of Arizona's industrial potential and its resources, we found that one of the largest single resources, our stand of ponderosa pine, a part of the largest single stand in the world, was very much underutilized. This wasn't a resource such as iron or copper ore that would stay in the ground unaffected and having no affect upon the water economy in this state. This was a resource that, by neglect, not only lost or delayed economic value to the state, but contributed to the intelligent use and preservation of its future value by such utilization. The method of this utilization is so important that it is the concern of all branches of the government. The Department of Agriculture, through its National Forest program and experiment stations, as well as state governments and a great many universities, are constantly concerned with the selected cutting and thinning of our forest area so that these timber lands will sustain themselves, both from a conservation and an economic standpoint. A good portion of this program is devoted to water and watershed programs.

Paper making and pulping is relatively new in the Southwest so we do not have any actual test of its affect on water yield or on sedimentation. This yield may later be determined on the Beaver Creek watersheds.

In Arizona the land manager's job is to maximize water yield. Tests show that three fourths or more of the water yield comes during winter and spring as the result of seepage rather than surface flow. So management is aimed at getting water into the ground. Water in the soil mantle perculates downward due to gravity and is pulled upward and lost through evaporation and transpiration. Many tests, such as Cowetta, Wagon Wheel Gap, Workman Creek, show that reduction in vegetation increases stream flow. This increase may be as overland flow or as seepage flow, depending on topography and precipitation pattern. We might, then, speculate that *reduced* forest cover will result in increased water yield, but the amount of forest reduction acquired for maximum water yield is something that we hope to know more about a few years from now. A major influence on a Watershed Program as affected by a logging operation, is the construction of roads, usually one to four miles per section. On the other hand, we must remember that vacuums are seldom tolerated in nature. Thus, when an opening is made in a stand of timber, nature usually will fill the vacant area with another plant.

Pulpwood harvest, in conjunction with regular timber harvest, would reduce stand density. This, in turn, may reduce interception loss, especially from snow, and also would be conducive to greater snow accumulation. The rate of snow melt should be more rapid and result in higher runoff peaks from spring snow melt. Pulping may eventually get into inferior kinds of timber, such as white fir, Engelmann spruce and aspen. However, the stand density reduction required to reduce soil moisture deposit in Arizona, is still not too well known at present.

As I mentioned before, we have the largest stand of virgin ponderosa pine in the world in Arizona. Prior to the construction of a paper mill at Snowflake by the Southwest Forest Industries, Inc., 80 percent of our utilized forest crop was leaving the state in the form of raw lumber and dimension stock. This left 20 percent of this resource remanufactured in the State of Arizona. Taxes, payroll, and value added by manufacturing on this 20 percent was a poor ratio to show for a resource this great. With the addition of a paper industry to the economy of Arizona, this vast forest area of more than 3 million acres, the largest timber sale in the history of the U.S. Forest Service outside of Alaska, is now the sound basis on which the Snowflake Mill is built. This contract allows a cutting of 300 thousand cords per year for 30 years. Cuttings are premarked on 1,600,000 acres of United States Forest Service forests. In Arizona, expectation is that pulpwood cutting will average two cords per acre.



In harvesting pulpwood for the paper industry, we must realize the economic impact on the area, such as new people, new homes, the needs of these people and their recreational needs.

A pulp market assures us that we can commercially cut trees 6 inches in diameter, breast high. This means that we can harvest the entire stand at this size (some sites can only grow small diameter trees because of the poor condition of soil) or we can utilize a portion of the timber stand when it reaches this size. This gives us the opportunity to reduce the density of tree cover, commercially about 40 to 60 years sooner than if we had only a sawtimber market. We have, then, much more flexibility in management.

The basal area of a tree is the cross-sectional area of the stem at 4.5 feet above the ground. In the United States, basal area customarily is calculated in square feet from the diameter outside bark. In young fully-stocked stands, basal area increases rapidly, but it levels off as the stands mature and usually does not increase in later years. This is, then, an unmanaged stand. Consequently, total basal area of the trees on a forest unit often is used as a measure of stocking.

In order to allow for better growth on the best trees, we are reducing overdense stands as much as 50 percent in basal area. This has the effect of opening up the forest floor for vegetation, allowing water to fall to the forest floor that would have previously been intercepted by the canopy and lost to evaporation.

When a stand of trees of pulpwood size is thinned its recreational value is increased. After thinning, trees are left well spaced and provide an enjoyable forest environment.

Southwest Forest Industries, itself, has 82,000 acres of forest checker-boarded with the government forests and a small amount of state forests lying mostly southwest of Flagstaff. There are three national forests which are under the U.S. Forest Service control and the White Mountain Indian Reservation of the Apaches, all of which will be drawn upon. These forests in the highlands of Arizona, which run gradually southeastward, include trees that are generally 150 to 160 years old. This is considered the age of full maturity; and there are many that are older and overmature. These provide sawmill chips, which are utilized in the Snowflake Mill. Ponderosa pine will furnish at least 85 percent of the pulp for the Snowflake Mill. Tests made at the U.S. Forest Products Lab in Madison, Wisconsin, showed a natural pulp brightness of 61 to 62½ for ponderosa pine news trials.

The Kraft pulp made from ponderosa pine has high mullen, good printability and good tear. This is perhaps the first time in this country that such a high percentage of ponderosa pine will be used.

Contract haulers have been supplying 75 percent of the sawlogs to the Southwest Mills for many years and this is the way most of the pulpwood comes in. The rest is logged by Southwest's own crews. At Snowflake, about two thirds of the 145,000 units of chips required will be produced in the company's two sawmills. The rest will come from pulpwood or other sawmills in the area.

The Snowflake Paper Mill is the only paper mill in the country that is not located on a river or a tidewater. The mill stands above a reservoir of saturated Coconino sandstone, 60 miles wide, 140 miles long, and 400 feet thick. This mill is assured of 30 million gallons a day for at least 100 years.

Three factors: distance of the well field from the mill, pumping costs, and the need for conservation, prompted a thorough investigation of water use in an effort to reduce to a minimum, the fresh water requirements of the mill. Consideration was directed toward affecting water economies that would be considered unusually low for conventional mills. The Snowflake plant is unique in the many ways water is saved and reused.

In evaluating Arizona's paper industry as related to Watershed Management and to the economy of the State of Arizona, I think we must conclude that we now have an industry in Arizona that at one time was considered unfeasible. I think the facts will show that selective and scientific utilization of our forest crop will facilitate growth and will facilitate a more qualitative crop. I believe the paper industry will greatly facilitate the studies of the forester and the Watershed personnel in experimentation in water utilization and will provide for more conclusive findings. The part the paper industry plays in this program is important in that it provides a market for trees that need to be removed to bring over-populated stands down to optimum stocking. While the paper industry is playing an integral part in the Watershed Program, it is employing more than 800 people with an investment of $40,000,000 and has contributed a major basic industry to Arizona and to the Southwest.

I mentioned, before, that Arizona was weak on wood remanufacturing. In addition to basic Kraft and newsprint, the Snowflake Mill is producing paper bags with a capability of 800 tons per month; and is producing mulch as a soil conditioner. The remanufacturing of containers and other products are located at Glendale, Arizona as well as Los Angeles and Chicago.

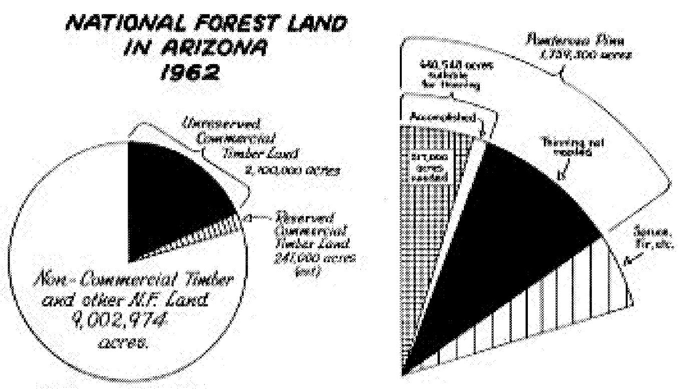
The paper industry is one of the most dynamic, versatile and progressive industries that exist today. The paper industry was built on research. The paper industry is in landlocked Arizona through research.

I am sure that intelligent use of our water and timber resources will compliment one another for a growing Arizona economy.

Thinning Ponderosa Pine

by **FRED H. KENNEDY,**
Regional Forester U.S. Forest Service

Timber stand improvement is an investment in the future. Blackjack poles that are pruned today will produce top quality lumber, or perhaps plywood, when they reach harvestable size. Seedling and sapling stands, properly thinned, will produce pulpwood within a few years; without thinning, none of us might see some of the more dense young stands produce mercantable products within our lifetimes. There are "fringe" benefits to thinning, which to many people are as important as those which affect the timber. I will mention these briefly after we take a look at what has been done in the past, and what lies ahead of us in improving the timber stands of the National Forests in Arizona.

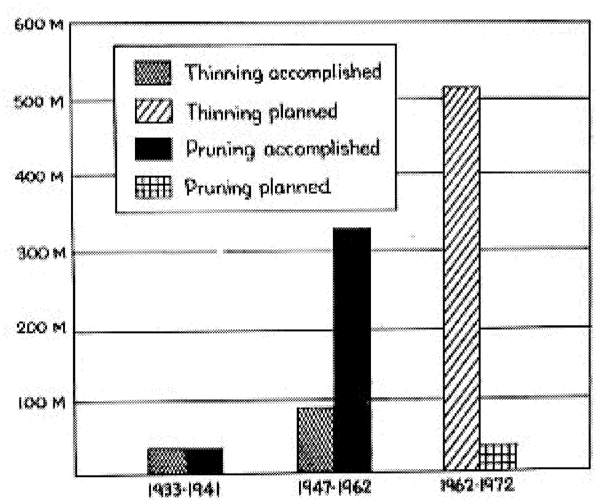


TOTAL: 11,343,974

Virtually all of the timber stand improvement work done on the National Forests in Arizona has been accomplished in two distinct periods. The first large-scale program came during the days of the CCC — between 1933 and 1941. After World War II, timber stand improvement work was resumed on the National Forests as part of timber sale receipts were allocated for cultural work on the areas from which timber was cut under the Knudsen Vandenberg Act. This "K-V" work is continuing, but it fluctuates rather directly with the volume of timber cut. During the past few years, appropriated funds have been available for timber stand improvement, and this has enabled us to step up the program measurably. Despite the fact that we have been working on this program during a 30-year period, making substantial progress, there is still a lot of work that remains to be done. If the President's "Development Program for the National Forests" is fully implemented, we will cover more ground in the next ten years than we did in the past thirty years.

During CCC days, the Forest Service did about as much thinning as pruning; about 32,000 acres were treated by each operation. Many of the same acres that were covered in the pruning operation were also thinned. This thinning was primarily a "release" thinning, aimed at providing growing room for the crop trees which were pruned. In most cases, we did not get into seedling-sapling stands. There was no foreseeable market for products like pulpwood, so there was little economic justification for treating these stands of small trees. Generally, we failed to thin heavily enough in the pole stands, and in some cases more trees were pruned than could be expected to reach sawlog size.

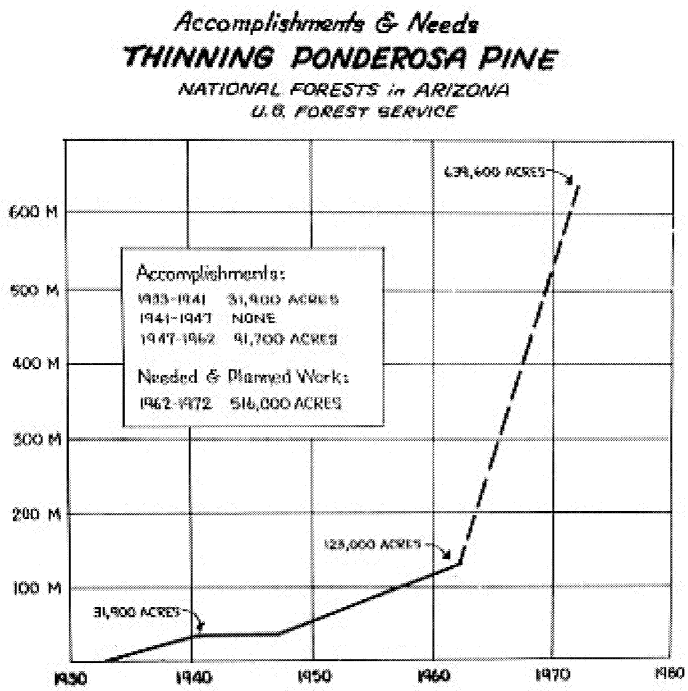
TIMBER STAND IMPROVEMENT
NATIONAL FORESTS in ARIZONA
U.S. Forest Service



The CCC work was good, as far as it went, and we have realized concrete benefits from it. Too, we have learned from it a lot of facts which are enabling us to do a better job today.

In the postwar period, especially during the first ten years, our timber stand improvement work was directed very heavily toward pruning to improve the quality of potential sawtimber. Over 335,000 acres were covered by pruning operations in Arizona since 1947. Release thinning was done to some extent, increasing in recent years, but pruning was dominant. Thinning totaled slightly under 92,000 acres in Arizona during this period. This approach was based on available research theory furnished by experts in ponderosa pine management.

This approach has been rather dramatically reversed in the past few years. For example in fiscal year 1962, we conducted uniform thinning operations on more than 14,000 acres in Arizona, while pruning was done on slightly less than 4,500 acres.



Some 28,000 acres have been covered by plupwood cutting since Southwest Forest Industries began operations. This market for pulpwood was a major stimulus in re-orienting our TSI program toward thinning. It coincided with some rather deep re-examination of our ponderosa pine silviculture in the Southwest. Ira Mason, Director of the Division of Timber Management in the Chief Forester's Office, summarized this in a report of an inspection in 1960:

"A lot of concern about overdense stocking of saplings and poles has been expressed over the years but very little has been done about it. Inaction in part has been due to the feeling that in due course dominance will be asserted by a suitable number of trees which will gradually progress to normal growth rates. Hence thinning from below has been presumed to be of little significance. Assertion of crown dominance in crowded pole stands is readily observable, but quite evidently crown dominance is not enough to gain release. The numerous overtopped whips show an amazing ability to stay alive and retard growth rates of the dominants.

"It is quite a shock to realize that after 41 years most of the areas stocked with the 1919 regeneration class are not yet ready for a pulpwood cut. This condition decisively demonstrates that in the Southwest, thinning of overdense poles from below is significant and essential. Without thinning we must put up with intolerably long periods in which stands will hang back in less than commercial size classes."

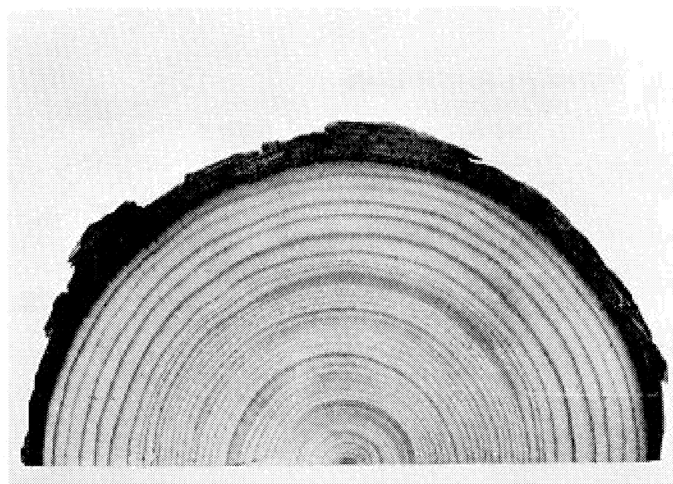
We are not going to put up with the situation thus described if we can help it. We are prepared to apply intensive cultural treatment to more than a half-million acres of ponderosa pine timber land in the next ten years. Most of this should be in the form of uniform thinning.

This treatment will be applied on the basis of site index, or the productive potential of the site expressed in terms of the height attained by a tree in a 100-year period. On sites with high productive potentials, stocking would be reduced less than on sites of low potential. At present, it is planned for stands of average potential to be cut back to about 80 square feet of basal area per acre.

"Basal area" is only one of several measures that can be used to express the density of a stand, but we find it the most useful one. It simply means the total cross-sectional area of all the trees on a given acre, measured at breast height. Even a relatively large basal area per acre actually represents a very small portion of the total land area (43,560 sq. ft.) in an acre.

Benefits of thinning are in many cases measurable. One of the most important of these is easy to demonstrate. Careful thinning shortens the rotation. That is, it materially reduces the span of years required for a timber stand to achieve harvestable size.

As an example, let's assume we have a newly regenerated stand on a site of average productive potential. Natural regeneration would result, say, in 11,400 stems. Left to its own devices, this stand would probably require as much as 250 years to reach the end of a natural rotation, where most of the trees were of merchantable (sawlog) size and declining in their over maturity. The rotation of course be shortened by periodic light selection cuts of sawlogs. Under this system, we have been working with a rotation of about 160 years in the Southwest.

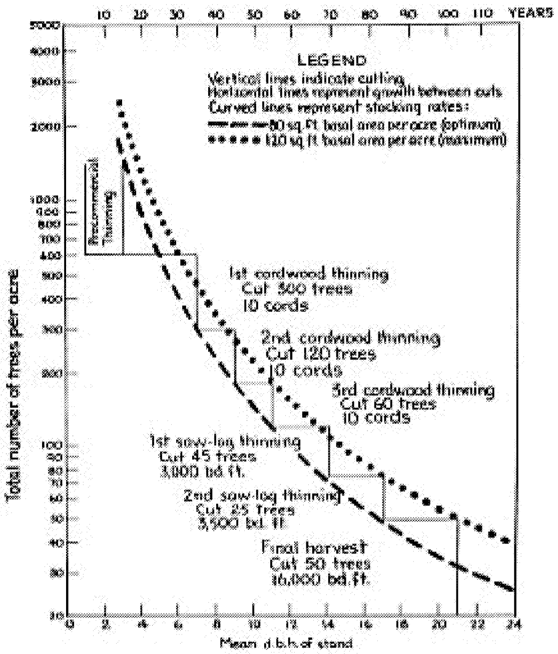


Dramatic increase in growth after thinning is illustrated by this section of a ponderosa pine pole thinned in 1954, cut in 1962.

If we introduce a precommercial thinning, plus two or three pulpwood thinnings, the length of time required to grow the sawlog trees to their culmination of growth can be reduced to only 120 years. In this shorter (by 40 years) period, the same amount of sawtimber in produced, but in addition, substantial amounts of pulpwood have also been harvested and put to good economic use.

A chart, published by Gaines and Kotok, in *Thinning Ponderosa Pine in the Southwest in 1954,* illustrates roughly how this might work. Numbers of trees, average diameters, basal area, volumes cut — all would vary, depending upon how good the site. Here, 80 square feet of basal area is used as the residual after-thinning level.

This chart does illustrate how the stand grows up beyond what may be considered optimum density, then is periodically reduced to a predetermined level and allowed to grow more rapidly until another cut is made in approximately 20 years.



Graphic demonstration of idealized stand management

Thinning, then, puts the growth potential of a site on fewer stems — where it can be used — rather than dissipating it on many stems which take excessively long to reach useful sizes. But this is not the only result of thinning. The quality of products is improved; a shorter rotation means less exposure time to insects, disease and natural hazards. In thinning, diseased and insect-infested trees are selected for removal, leaving those which are healthy and vigorous in their resistance to attack. Thinning offers some hope for solving part of the dwarf-mistletoe problem that has caused us increasing concern over the years.

Some silviculturists feel there is a genetic advantage to thinning; if the parent trees have desirable characteristics, there is a better chance that the young trees will also have good qualities.

It might be theoretically desirable, from a strictly silvicultural standpoint, to thin so that each element of the site — water, light, soil fertility and growing space — would be fully utilized in the growth of wood fiber on trees. This isn't possible because the site elements are seldom, if ever, present in the precise ratio required by the trees. It isn't practical, because thinning must be limited to once each 20 years or so. The stand is to be a lower level of basal area than will fully use the site, and it exceeds the point of optimum growth before it is thinned again. The point here is this: thinned stands leave room on the site for production of other resources.

Water yields from thinned areas are being measured at Beaver Creek, and some preliminary indications of effects should be forthcoming within the near future.

There are already strong indications that thinning of the type we are doing will increase forage yields.

Thinning ponderosa pine produces increased forage, as proved by Forest Service research conducted in the Black Hills National Forest in South Dakota. Studies showed a very strong relationship between increasing forage (including browse) production with decreasing timber stand density. There are indications from studies on the Beaver Creek Watershed Pilot Project that we are getting the same general trend of results from our thinning work here in Arizona.

A study watershed thinned in 1956 and 1957 produced about twice as much perennial grass as did untreated pine stands four years after treatment. In 1960, 127 pounds per acre of air dry forage was produced under a stand thinned to approximately 80 square feet basal area, while the average of untreated pine stands was only 64 pounds. The following year, with more rainfall, production was 251 pounds and 117 pounds respectively. These results are not conclusive, but they do indicate that there is a difference. A more comprehensive study of the effects of stand density is getting under way on the Coconino National Forest in the Wild Bill area. Seven pastures are being set up; one will be untreated, 4 will be thinned to 80, 60, 40, and 20 square feet basal area respectively, and two will be cleared of all trees. One of the latter will be seeded to grass and legumes, the other left without seeding. These pastures will be grazed, giving us a practical measurement of results in terms of beef production as well as forage production.

Wildlife, too, benefits from thinning. Besides increased production of forage (browse), open stands facilitate movement of wildlife (as well as livestock). More open stands make harvesting of the wildlife crop easier. In connection with pulpwood cuts and precommercial thinning, "invader" trees are being cut from natural meadows and parks to maintain essential openings for game and domestic animals.

Thinning will ultimately simplify the job of fire control, once initial slash accumulations have broken down. "Doghair" thickets present a formidable fire hazard. Reduced in density, these stands will be less likely to support sweeping crown fires. In the first few years following thinning, these will be accumulations of highly inflammable flashy fuels on the ground. These present us with a slightly different, if not more dangerous, fire control job than we have when this material is on green trees. We have a formidable fire control job on areas supporting these stands whether thinning is done or not. However, once the relatively light, small material breaks down, (which is does rapidly, compared to heavy fuels left by sawlog operations), our fire control job will ultimately be easier than it was before thinning.

As in sawtimber harvesting, we are doing some slash disposal work following thinning to break up concentrations and to provide positive, immediate protection to high-value areas.

As indicated by this discussion of fire hazard, there are problems inherent in conducting large-scale thinning operations. A potential one is insect infestation. For example, bark beetles can build up rapidly in slash, spreading to green trees when green slash is no longer available. No major insect problems have developed as yet, but we feel that we must be alert to the ever-present danger.

Another problem, if you want to call it that, is this: thinning costs money. Precommercial thinning, including additional work required after pulp is harvested, is costing about $20.00 an acre. On a larger scale, there may be opportunities to reduce unit costs, but we are constantly faced with rising costs of labor and equipment while endeavoring to do a better job on the ground.

An important key to success in thinning is the supervision given the work. Specially trained men are doing the work of selecting trees for pulp harvest, and experienced professional foresters prepare prescriptions for conducting precommercial thinning. These men train and inspect the work of crews doing the actual thinning, for mistakes made at this point are decades in the correcting.

The old-fashioned axe is still used in precommercial thinning, but it is being rapidly replaced by motorized saws. Circular saws are well adapted and are highly effective on small stems. For larger stems, the power bow-saw is the best tool we have tried to date; it is used by a two-man team, one member of which uses a pusher stick to prevent binding and guide the fall of the tree.

We are still seeking machinery that will help us do a more economical job without sacrificing any quality in tree selection. In extensive, rather uniform young stands, we see possibilities for using some type of heavy equipment to cut, flail or plow swaths through the stand in a grid or strip pattern. This would have to be followed up by handwork or light machinery (saws) to thin the squares or strips left by the heavy equipment. Several machines show promise, but to date, we haven't found anything that will give us lower costs than an efficient crew using saws and axes.

Continued refinement of our silvicultural guides and multiple use prescriptions will have high priority as we go ahead with thinning on an increased scale.

I may have given the impression that the work accomplished to date, plus the half-million acres we need to do in the next decade will pretty well wind up the thinning job and we will go on to some other task. This isn't the case; we'll be doing thinning probably as long as we are managing ponderosa pine. As each rotation comes to an end and is regenerated, we will have more opportunities to gain increased quality and growth by thinning.

This final thought I want to leave with you: thinning is an essential silvicultural practice, but it is more than that. It is a multiple use management practice. It benefits other important resources as well as timber. As we learn more from research and from pilot projects like Beaver Creek, I am sure we will find opportunities to modify thinning guides and practices for some sites on some areas to provide added benefits to other resources as demand and wise management dictate.

Thinning is not the answer to all of our problems, but the program now under way is soundly based, and it is one of the major steps the Forest Service is taking in the Southwest to intensify management under the multiple use principle.

Hydrologic Models of Ground-Water Movements

by H. E. SKIBITZKE,
Research Mathematician
Water Resources Division, U.S. Geological Survey

The Water Resources Division of the U. S. Geological Survey has developed a diversified interest in computer techniques. These techniques extend from the use of digital computers to the use of sophisticated analog computer equipment. The digital techniques are applied over a range of problems extending from accounting to the handling of surface - water stream - gaging records. To expedite and economize on data handling the Water Resources Division has a large-scale installation program of digital recording instruments, in the water-stage recorders of the Surface Water Branch. The evaporation modification technique studies have also required the measurement of several factors causing evaporation from water surface. Most of this instrumentation has been of a digital nature.

The equipment that collects and processes digital information allows data to be handled more efficiently and with less manpower. This is not the only purpose in applying analog techniques in the Division. Analog techniques have allowed solution of many problems that engineers would be unable to cope with. The computer work can be separated into two principal fields; the development of ground-water computer techniques and the development of surface-water computer techniques.

The computer techniques applied to ground-water problems are most often of an electronic nature. Ground-water levels are controlled by capillarity to a certain degree. The effects of capillarity make the construction and operation of hydraulic models quite difficult in answering problems involving ground-water head. By head is meant the height to which water level will rise in a well. The water-level rise in a well is generally the economic entity in which the community is especially interested. Because this is true the prediction of the change in water levels is a factor that is generally of most interest to the community with reference to its ground-water development. In nature the several-foot or more capillary rise that occurs in an aquifer is insignificant in analyzing engineering problems, but in small-scale laboratory experiments several feet of rise caused by capillarity would vitiate the hydraulic model results. Thus the use of electrical networks to analyze ground-water flow problems has proven particularly useful. In the Phoenix Research Office the Water Resources Division has established a laboratory to construct electronic computer models for solving ground-water problems for any of the Division district offices throughout the United States. Figure 1 shows one of the electric analog models of a ground-water aquifer. In figure 2, a technician is shown checking out the analyzer equipment used to simulate removal or addition of water in the aquifer and to determine the resulting changes in water levels.

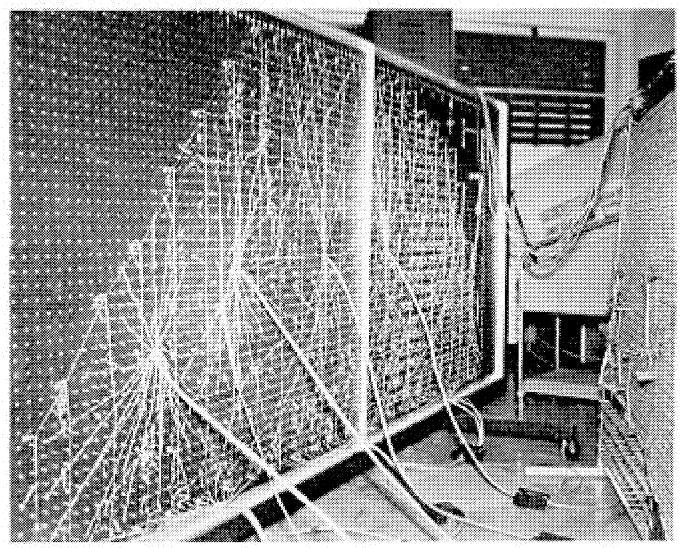


FIGURE 1. Electronic model of a ground-water aquifer.

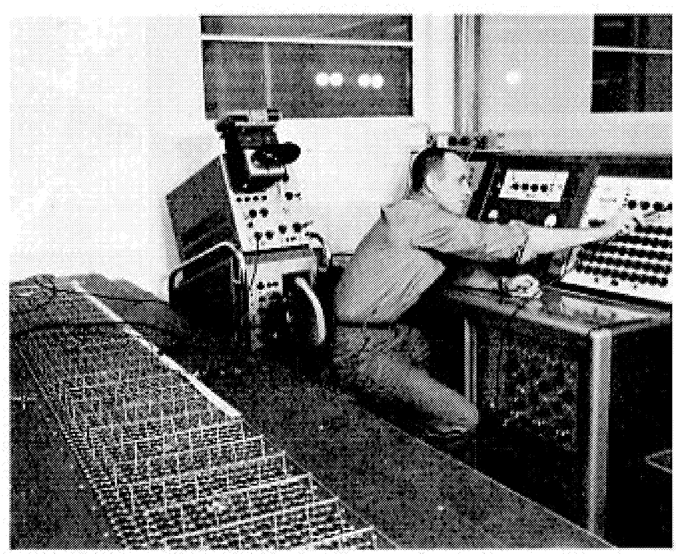


FIGURE 2. The analyzer of an electric analog computer.

In addition to studying problems involving ground-water head or potential extensive studies have been launched regarding the dispersion of dissolved components in ground-water systems. An experiment of this type is shown in figure 3. This is a substantially different problem from those concerning head or potential, so that hydraulic models can be effectively used in the laboratory. Several hundred experiments on models already constructed illustrate principles of ground-water flow with reference to the dispersion of dissolved components. These experiments are being described for publication in reports by the Water Resources Division.

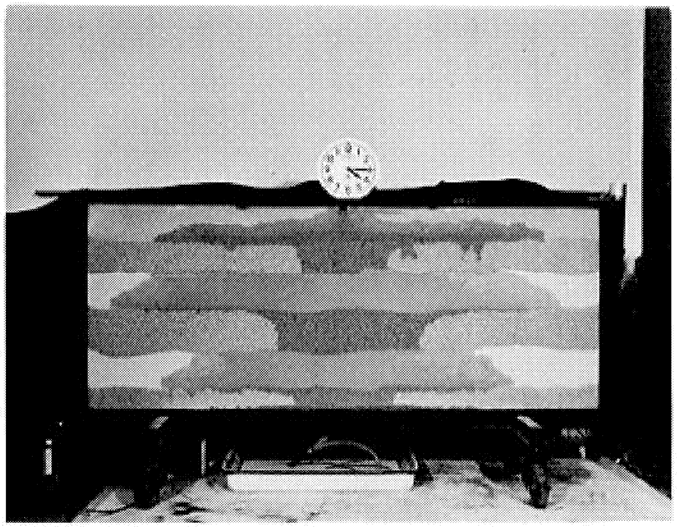


FIGURE 3. Hydrologic laboratory model of horizontal layers above the water table.

The hydraulic models illustrating dispersion provide results having immediate practical application in engineering analysis of the effects of contamination of ground-water systems. The models are operated with tracer-tagged fluid that moves at rates proportional to the rates that will occur in the field-scale project. The model scales are chosen so that time and physical dimensions are suitably proportional to the actual ground-water system. An experiment of this type is shown in figure 4 and the results are shown in figure 5.

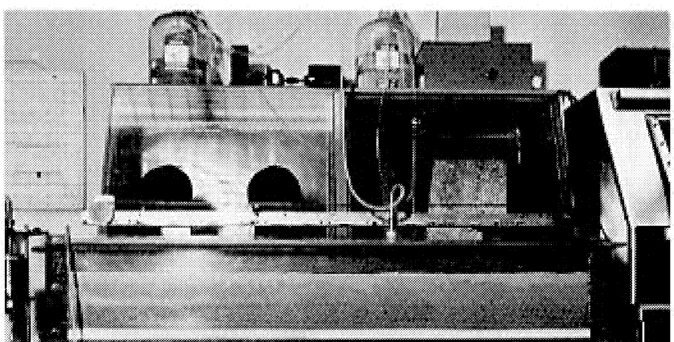


FIGURE 4. Hydrologic laboratory model of ground-water formation.

The development of surface-water computer techniques in Phoenix has followed two lines. One approach is the development of computer methods necessary to calculate the surface-water outflow from an area in response to a given input of rain. The mathematical techniques for accomplishing this are familiarly known by the term "unit hydrograph analysis". The simplifications and idealizations that necessarily limit the mathematical analysis are not necessary and therefore do not similarly limit the electronic computer techniques being developed. At the present time equipment for computing the amounts of outflow due to an

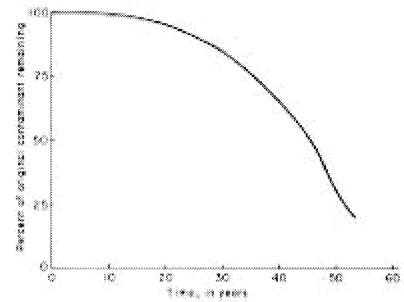


FIGURE 5. Graph showing replacement of original liquid in the model shown in figure 4.

input of rain are capable of taking into account the land surface area, slope, evaporation, and other factors that represent environmental controls on surface-water flow.

In addition to determining factors used in the unit hydrograph forms of analysis electronic computers are being applied to the development of functional relationships pertaining to reservoirs used for flood control or water storage. These reservoirs have storage fluctuations that depend upon the random fluctuations of rainfall. In a sense these are not predictable; however, in the sense of long-term averages there are functional relationships that may be determined by electronic computing methods. As an example, techniques have been developed for determining the cyclic occurrence of floods or of minimum flows, and their reflections or responses in the reservoir systems can then be predicted.

The problem of determining the relationship between cause and effect, involving some hydraulic parameter, can be handled in the computer laboratory. Usually this requires the development of a technique for initiating disturbances analogous to those found in nature. For ground-water systems the initiating influence reflects the activity of man. Thus the community decides where and how it proposes to pump ground water. The consequence of this pumping, in terms of the distribution of drawdown throughout the aquifer, can then be made by the computer. Since the drawdown relationship affects any new well and the depth-to-water level below the community, it is desirable to predict ahead of actual construction the consequences of alternative choices for new water-supply developments. The choices usually involve quantity of water to be pumped and position of the wells. Ordinarily decisions can be made from geologic information. However, in the last few years the interrelated effects of community economic and sociologic factors have rendered the decisions more complex. Man's freedom of choice is now limited partly by the complex feedback of economic and sociologic factors. A certain degree of randomness can also be added. These particular developments are for application to ground-water computers. Hopefully some of the factors that will affect water-supply development in the next fifty or sixty years can be analyzed. And the analysis is always most conveniently presented in terms of the effect of water-level changes in time.

The surface-water computers require input functions that are most often not chosen by man alone. The choice is usually dictated by nature, and modified somewhat by the activities of man. These are difficult functions to derive for computer use. The random effects of rainfall, which becomes the driving factor involved in surface-water runoff, are not as simple as it might appear. The rainfall significant to surface-water runoff is not calculable from weather phenomena alone. Usually the factor that causes runoff is only that portion of the weather that causes intense rainfall to occur. It is therefore necessary to determine what part of the regional weather phenomena would result in intense rainfall. Furthermore the rainfall is localized by the effects of changes in topography or surface conditions, such as heating. Therefore, there is a spatial relationship highly dependent upon the environment itself that controls the amount of rain and particularly the amount of intense rain that would fall on a particular watershed area.

It is necessary, therefore, to develop a technique for measuring the factors causing rainfall to occur. A direct application of these measurements could then be made to an analysis of the observed runoff in streams. Measurement of these characteristics in the past has required installation of a large number of gaging stations. In arid regions this would require such an extensive network that the expense of operating the gaging stations would not be feasible. Accordingly more modern techniques have been devised. Radar is being developed by the Phoenix Research Office for determining the input function to a computer that would predict runoff several hours ahead of its occurrence, based on data concerning ontecedent rainfall. This would allow scheduling or planning for the effects of flood crests. More important, this type of study will aid the engineer to analyze the type of rainfall that has produced the unit hydrograph.

After the previously described goals are achieved it will be desirable to construct electronic simulation and prediction devices. In essense this would mean artificially portraying on an oscilloscope screen, in a few seconds time, events that might represent a thousand years of rainfall across a watershed area. This device should contain the local factors of topography and land-surface conditions. These effects coupled with the observed randomness of the cyclic variations in rainfall could be put into the electronic instrument. The output then would be functions or pulses analogous to the heavy rainfall that would cause runoff. These pulses would be used as the driving functions for computer linkages that would in turn predict the resulting streamflows. Thus an electronic analysis made over several seconds of time, simulating perhaps a thousand - year record, foretells what to expect in the occurence of flood crests and variations in the normal stream flow in an area. This would be the ultimate goal in surface-water studies.

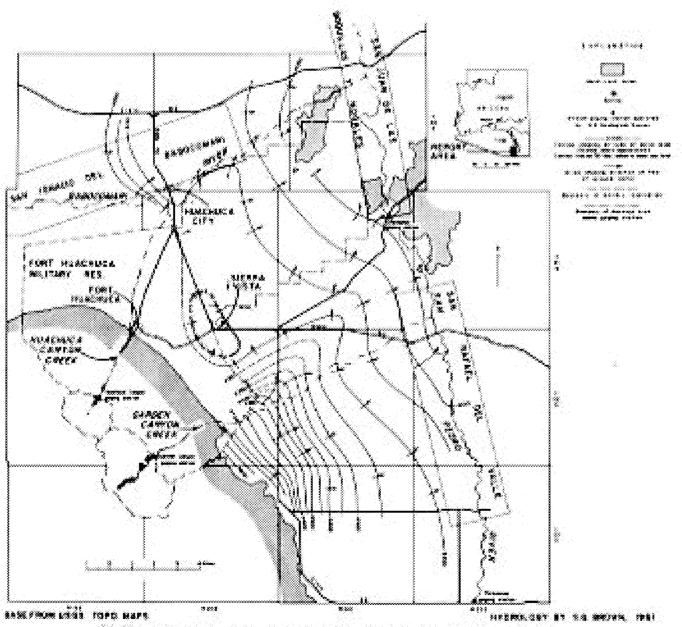
The research necessary to determine what factors locally cause the heaviest rainfall to occur, and what portion of the weather phenomena is significant to the heavy rainfall factor, must be expended. Research in Phoenix will continue on the development of techniques for predicting runoff when the input functions are known, as well as devices for furnishing realistic input functions. The ultimate objective in research is to establish for man and his environment the relationship between cause and effect insofar as this concerns hydrologic changes that have been and will be observed.

Possibilities For Future Water-Resources Development At Fort Huachuca, Arizona

By
S. G. BROWN 2)

Fort Huachuca, the U.S. Army Electronic Proving Ground, is in Cochise County in the southeast part of Arizona about 18 miles north of the International Boundary on the left bank of the San Pedro River—a northward-flowing tributary of the Gila River. The area covered in the study extends eastward from the crest of the Huachuca Mountains to the San Pedro River and southward from the San Ignacio del Babocomari land grant to an east-west line through Hereford, about 7 miles north of the International Boundary (fig. 1). The main part of the Post is at an altitude of about 5,000 feet. The average annual precipitation at the Post is about 16.5 inches, but it is estimated that it may be as high as 25 inches near the crest of the Huachuca Mountains.

When the Post was first established in the late nineteenth century, water was one of the deciding factors in



1/ Publication authorized by the Director, U.S. Geological Survey.

locating it at the mouth of Huachuca Canyon where springs occur. As the Post grew the spring flow from Huachuca Canyon was insufficient, and it was necessary to obtain additional water from the large springs in Garden Canyon—called "Tanner Canyon" on some old maps. The springs proved inadequate to supply the Post, and before World War II the first well was drilled near the East Gate entrance, near what is now Sierra Vista.

Because of the mobilization and growth of the Army before and during World War II, the U.S. Geological Survey was asked to aid in locating and developing adequate ground-water supplies for the expanding installation. Five producing wells were drilled during this program.

In 1959 the Survey was asked again to study the water resources of the Fort Huachuca Military Reservation, in order to determine where and how additional water could be obtained for the Post supply when it is needed.

An inventory of all existing wells in the project area was made. The existing statewide observation-well network was expanded to more completely delineate the water table and to better define areas of recharge and discharge and the direction of ground-water movement. Well-production data were obtained from drillers, private well owners, and public agencies. Although many springs near the military reservation were visited, the major effort of gathering spring and streamflow data was expended on the military reservation. A stream-gaging station was constructed near the mouth of Garden Canyon Creek in October 1959, and the flows of the major springs in Garden and Huachuca Canyons have been measured regularly since that date. In November 1961, a gaging station was constructed in Huachuca Canyon. Water-level recorders were installed on three wells on the reservation. Two of these were near the Post well field and were of value in determining and extrapolating the effects of pumping. Pumpage data for the Post well field were collected from the records of the Post Engineer, and aquifer tests were conducted. Geologic data are being compiled and a final report is being prepared.

On and near the Fort Huachuca Military Reservation ground water occurs in the fault-zone springs in the hard rock of the mountains, and in the alluvium that fills the valley of the San Pedro River.

The source of the springs in the Huachuca Mountains is runoff from precipitation and snowmelt intercepted by the more porous joints and fault zones. These zones quickly transmit water to the springs.

The source of the ground water in the valley alluvium is runoff along the mountain fronts and the upper reaches of washes where they debouch from the mountain canyons onto the valley slopes. Surface flow seldom extends from the mountain fronts to the San Pedro River, except during periods of brief but torrential precipitation in the summer. Most of the surface flow that emerges from the canyons is lost to evapotranspiration—that is, evaporation from surface water or from shallow ground water and consumptive use by plants. A very small amount of water enters the soil and continues downward to the ground-water reservoir. Then, as ground water, it moves down the hydraulic gradient and eventually reaches the San Pedro River. Much of the ground water beneath the flood plain of the San Pedro River is transpired by bottom-land vegetation or is lost by direct evaporation from the shallow water table. Some water also is forced to the surface by rock cropping out in the channel and is measured as Charleston gaging station as part of the surface flow.

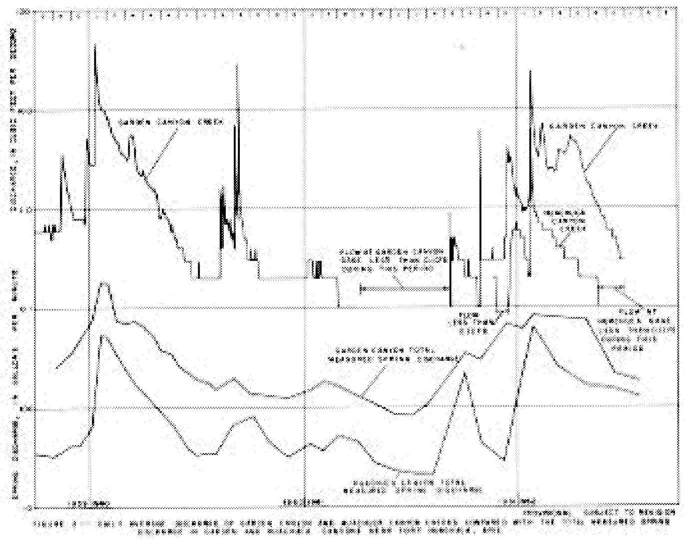
Figure 1 is a water-table contour map, constructed from depth-to-water measurements in 48 wells, showing the shape of the water table near Fort Hauchuca for March 1961. The arrows show the direction of movement of the ground water from the recharge area near the mountain front to the discharge area along the San Pedro River and to the cone of depression around the Fort Huachuca-Sierra Vista well field. A prominent ground-water mound is apparent along the mountain front at Garden Canyon. The arrows indicating the direction of flow show that Garden Canyon Creek and its associated underflow contribute recharge to the Fort Huachuca-Sierra Vista area. In brief, the water-table map for March 1961 shows that ground water is recharged to the alluvium along the east face of the Huachuca Mountains and moves down the hydraulic gradient to the San Pedro River where it is discharged by evapotranspiration and by seepage to the flow of the San Pedro River. An additional means of ground-water discharge is by pumping from wells. In the Sierra Vista-Fort Huachuca-East Gate area, the cone of depression caused by pumping is readily apparent.

The well field at Fort Hauchuca consists of six wells capable of producing more than 5 mgd (million gallons per day). This is more than sufficient to supply the present needs of the Post. However, long-term water-level data showed that the water table was declining regionally at an average rate of about 0.5 foot per year with only minor pumping for stock and domestic use. This small amount of pumping certainly is not enough to cause a regional decline, indicating that recharge to the saturated zone is insufficient to maintain the water table at a higher level even under near natural conditions. Water levels in wells in the Fort Huachuca-Sierra Vista well field were declining at rates of about 3 feet per year. Increased pumping at Fort Huachuca and nearby Sierra Vista, Huachuca City, and the surrounding housing developments will cause the rate of decline to increase. However, the valley alluvium provides a large storage reservoir from which water can be obtained easily by wells in the quantities needed. The amount of ground water in storage is large compared to the natural recharge to the alluvium, but when ground water is pumped out faster than it can be recharged it is being mined and the aquifer is being depleted.

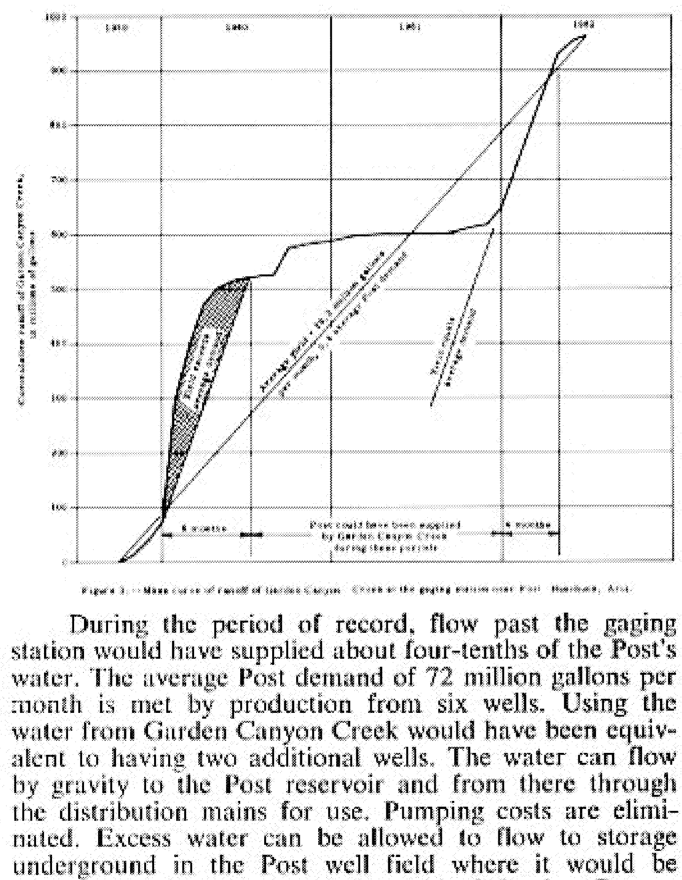
On the Fort Huachuca Military Reservation surface water is derived from (1) storm runoff, (2) snowmelt runoff in winter time, and (3) discharge from springs into the stream channels of Garden, Huachuca, and other canyons.

The discharge of Garden Canyon Creek has been measured at the gaging station near the mouth of the canyon since October 1959. Measurements of spring discharge have been made at least monthly at three places in Huachuca Canyon and at four places in Garden Canyon. Hydrographs of the daily average discharge of Garden Canyon Creek and of spring discharge in Garden and Huachuca Canyons are shown on figure 2, as well as a short hydrograph of runoff past the Huachuca Canyon gaging station.

A mass curve of runoff measured past the Garden Canyon gaging station is shown on figure 3. At the end of June 1962, 33 months after the installation of the station, 2,960 acre-feet of water had flowed past the station — an average of about 29.3 million gallons per month. Average production from the Post well field from October 1959 to June 1961 was 2.4 mgd, or about 72.0 million gallons per month; production ranged from 104.2 to 43.7 million gallons per month during this period.



2/ *U.S. Geological Survey, Tucson, Arizona.*



During the period of record, flow past the gaging station would have supplied about four-tenths of the Post's water. The average Post demand of 72 million gallons per month is met by production from six wells. Using the water from Garden Canyon Creek would have been equivalent to having two additional wells. The water can flow by gravity to the Post reservoir and from there through the distribution mains for use. Pumping costs are eliminated. Excess water can be allowed to flow to storage underground in the Post well field where it would be available to the wells when the yield of Garden Canyon drops below Post demand. The shape of the cone of depression and the alignment of the wells in the Post well field would allow recovery of most of the recharged water.

Underflow in Huachuca and Garden Canyons could provide a source of readily available water. In the early fall of 1959, a large excavation was made in Huachuca Canyon near a group of springs. Surface flow from these springs was small. The excavation extended almost across the canyon floor and to an estimated depth of more than 25 feet. The excavation encountered ground water at shallow depth and more than 200 gpm (gallons per minute) was pumped from the excavation in an attempt to allow work to continue "in the dry." No surface water was flowing in the canyon and precipitation had been light. By means of a suitable infiltration gallery, this water could be obtained at relatively small expense and conveyed by gravity directly to the Post reservoir. A similar area in Garden Canyon about a quarter of a mile above the gaging station could be developed in the same way.

Proper development in accordance with the geologic setting could increase the reliable yield of the springs in Garden and Huachuca Canyons and provide water for use on the Post. During periods of excess runoff these springs would provide water to be recharged artificially to the Post well field.

Development of the spring system and the practice of artificial recharge by the Army will be an important step forward in a more economical and more efficient use of the water resources available. Municipalities similarly situated and, before this, dependent upon a ground-water mining operation for their supplies, may be encouraged toward a more efficient use of flood runoff and winter streamflow that otherwise would be lost.

Only a small part of the runoff is recharged to the saturated zone, and capturing flood flows and winter runoff for recharge through pits or wells would augment the water supplies for many places in Arizona. At Fort Huachuca, the mass curve (fig. 3) showed that the amount of water available from Garden Canyon Creek alone would equal about 40 percent of the Post's average demand. An extra 40 percent is worth anyone's effort.

Controlled Burning of Arizona Chaparral A 1962 Progress Report

by A. W. Lindenmuth, Jr., and G. E. Glendening
Research Foresters2

Land managers must control fire if intentional burning is to find a place as a recognized tool for managing chaparral lands in Arizona. The burning period and fire behavior must be in accord with a preconceived plan. This progress report describes a test of a model for prescribed fire in Arizona chaparral.

The first question to be answered was: "Can mixed chaparral be treated to make it burn at times when untreated brush resists burning, so that the fire can be confined to the designated area without special controls?"

1 Acknowledgment is made to the Division of Fire Control, State and Private Forestry, and the Tonto National Forest, Southwestern Region, U. S. Forest Service, who planned and executed the burning operations; to Dr. D. T. Lillie, U. S. Agricultural Research Service, Tempe, for advice concerning the chemical spray; and to James R. Davis, Flagstaff, and C. P. Pase, Tempe, staff members of the Rocky Mountain Forest and Range Experiment Station for their contributions in planning the chemical treatment and evaluating the results of the burning.

2 Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, with central headquarters located at Fort Collins, in cooperation with Colorado State University. Mr. Lindenmuth is located at Flagstaff, in cooperation with Arizona State College; Mr. Glendening is located at Tempe, in cooperation with Arizona State University.

BASIC CONSIDERATIONS

Theoretically, one way to confine fire to a preselected portion is to create a large difference in moisture content between brush to be burned and brush to be left unburned. Spraying with chemicals to kill parts of plants and thus lower their moisture content is one method of creating a moisture differential. If this chemical treatment and burning is carried out during periods of the year when the moisture content of brush is naturally high, a relatively large moisture differential should result. This should make it possible to burn treated brush at a time when untreated brush resists burning.

An auxiliary question arose immediately: Assuming this type of burning to be possible, can burning be done in narrow strips so soil movement will not be increased greatly? Wild fires often result in serious erosion and large quantities of sediment are dumped in streams. Burning in narrow strips is one way to decrease the risk of accelerating soil movement. Any soil moving from burned strips should be trapped by adjoining unburned strips.

A MODEL TEST

With these considerations in mind, a model, or idealized exploratory test was designed. In this kind of test, ideal values are assigned to factors expected to have an important influence on the outcome. This improves the chance of getting an affirmative answer. The assigned values do not have to remain constant throughout the test. If values closer to ideal are found, they can and should be used. The objective is to get a "yes" or "no" answer to the question asked, and not to test specific values, treatments, or procedures.

A study area consisting of three small watersheds was selected on the Sierra Ancha Experimental Forest in central Arizona about 35 miles north of Globe. Strips 200, 100, and 50 feet wide were assigned to individual watersheds (fig. 1). Replication of the burning for four successive years is planned to: (1) strengthen the answer to the question regarding burning by prescription and (2) to provide a basis for evaluating the effects of strip-burning entire watersheds on soil movement. If the initial series of burns shows promise, the experiment may be extended to include a second series of burns on the same strips as a basis for getting firmer answers to both questions.

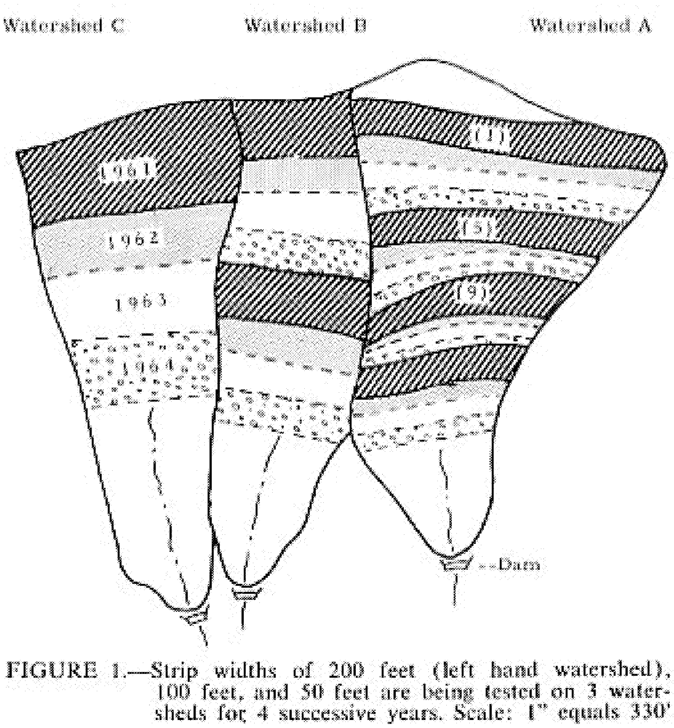


FIGURE 1.—Strip widths of 200 feet (left hand watershed), 100 feet, and 50 feet are being tested on 3 watersheds for 4 successive years. Scale: 1" equals 330'

Analysis of weather records showed that September 17 to 22 was a uniquely dry period following the "summer rains" in the Sierra Ancha area. This period was therefore selected as most ideal for burning — brush should have a high natural moisture content, and there should be small chance of weather interfering seriously with the burning for more than short periods.

It was decided to spray 6 weeks ahead of the burning date with a mixture of 2, 4-D, and 2, 4, 5-T by helicopter.

This decision was based largely on general experience gained in other regions rather than on actual tests in Arizona. Although this might not be an ideal treatment in Arizona, it offered the most promise at the time. During the course of this test, changes may be made to bring the treatment closer to ideal.

FIRST-YEAR ACCOMPLISHMENTS

By the end of August treated leaves had dried to about 10 percent moisture, whereas, untreated leaves contained more than 90 percent (fig. 2).

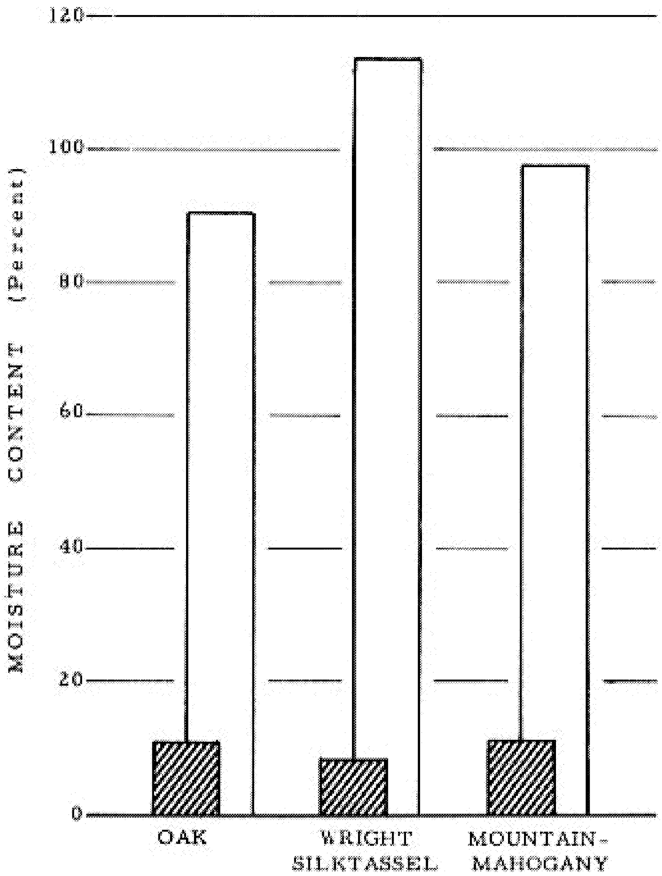


FIGURE 2.—Moisture content of treated leaves (shaded bars) ranged from 8.3 to 11.4 percent; untreated leaves ranged from 90.5 to 113.5 percent.

The treated strips were burned as planned on September 19, 20, 21, and 22, 1961, (fig. 3). The adjacent untreated areas appeared resistant to fire, and there was no notable tendency for the fire to spread out of bounds. We cannot say, however, that the fire prescription tested is safe without having fire control facilities available.

The combination of spraying and burning did a good job of top-killing the brush (fig. 4). Live brush cover was reduced by 93 percent. Ordinarily, a single foliage application of phenoxy herbicides, such as 2, 4-D, or 2, 4, 5-T, without burning, is expected to reduce the living crown cover by roughly 30 percent.

Consumption of leaves and small twigs on the ground averaged 29 percent. There has been no immediate evidence that burning aggravated soil movement. There have been no high-intensity storms since the fire, but the total precipitation of 13 inches for the October 1, 1961-May 1, 1962 period was approximately normal.

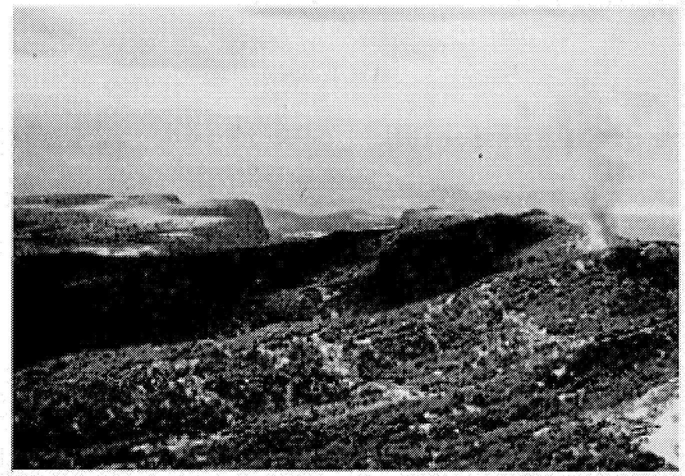


FIGURE 3.—View of the experimental area showing burned strips (1, 5, and 9) in the foreground (watershed C) and burning in progress in background.

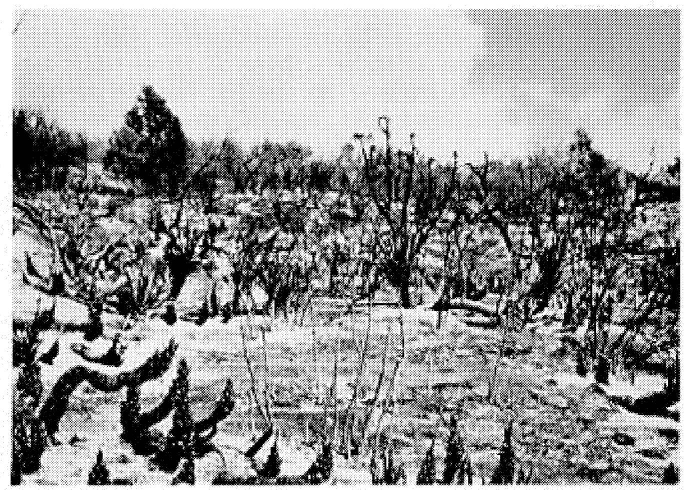


FIGURE 4.—Top killing by combined spraying and burning was nearly complete (93 percent average).

Considerable variation in flammability among species was noted on the sprayed strips. Whether this is linked to differences caused by spraying or to other factors is not yet known. Wright silktassel, Emory oak, and shrub live oak appeared to burn well. Mountain mahogany and the manzanitas were less flammable. The failure of manzanitas to burn readily was a major surprise. These observations may be modified as the test progresses.

Nonsprouting species, notably desert ceanothus and the manzanitas, produced many seedlings during April 1962. By mid-August, however, roughly 90 percent were dead, apparently from drought and rooting by javelinas.

SUMMARY

1 — The treated strips burned as planned, without spread to adjacent untreated areas.
2 — The combination of spraying and burning produced a 93 percent reduction in live brush cover.
3 — Organic litter on the ground was reduced 29 percent.
4 — Soil movement during a winter of normal precipitation was not increased.
5 — Under conditions of this test, Wright silktassel, Emory oak, and shrub live oak appeared to be flammable; mountain mahogany and the manzanitas appeared to be less flammable.
6 — Though not conclusive in itself, the initial burning was rated a success and has provided justification for continuing the investigation of fire as a tool in managing Arizona chaparral.

Watershed and Game Management

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Introduction

This is a report on early stages of some investigations by the Arizona Game and Fish Department on effects of watershed treatments on big game, especially deer. Most of these treatments will make drastic changes in wild plant communities, for the primary purposes of testing or demonstrating effects on water yield. Generally initial changes in vegetation will be obvious, but other important ones could occur for many years, as influenced by natural ecological succession and continuing efforts to control it. The apparent effects of these series of changes on game are being deduced largely from degrees of use of the areas by game, and from observed effects on certain plant species valuable to game as food or other life necessities. Production and condition of the animals are also noted on some of the larger experimental watersheds.

Pine Type

The ponderosa pine type is one of the more important deer-producing zones. An estimated 27 per cent of the deer harvested in Arizona in 1961 came from pine and pine-oak areas. Watershed-wildlife studies in this type are under way south of Flagstaff, on the Beaver Creek areas. Most of the pine watersheds selected for study there are still in the stage of calibration to determine water yield prior to treatment, but two have already been treated. Game use on them, as indicated by droppings, has been estimated for two and three years following the initial vegetation changes. 1

Game were much attracted to a newly created grassland with abundant herbaceous forage, surrounded by large areas of pine forest. On that small converted watershed, summer deer use was significantly greater than the average use on six untreated pine watersheds in 1960 and 1961. Elk pellet groups were also much more abundant on the cleared watershed than on the nearby pine areas. A noncommercial stand of pines with some oak and juniper originally occupied the cleared watershed. In 1958-1959, the trees were removed, it was seeded to grasses and legumes, and livestock were excluded. Its area is about 150 acres; combined areas of the six untreated pine watersheds compared with it was estimated at more than 6400 acres.

Deer seemed neither especially attracted nor repelled by another treated pine area, a large watershed of approximately 2300 acres at Beaver Creek. On it, pine was thinned and pruned and attempts were made to kill deciduous oak trees *(Quercus gambelii)* by poisoning. Summer use of that watershed by deer has not been significantly different from use on the six untreated pine areas mentioned above, according to pellet sample data. Nevertheless, some wildlife effects of that treatment may show up in other years. Poisoning killed the large oak trees, which are the principal acorn-producers. Abundance of a rich food such as acorns possibly has an important effect on wildlife breeding success and survival of young immediately following good mast crops, although the latter do not occur every year (2). As yet, there are too few years of records at Beaver Creek to permit a statistical estimate of expected frequency of acorn abundance, or of possible correlation between crops of acorns and fawns.

1. Field work on the Beaver Creek estimates of game and hunter use has been done jointly by the United States Forest Service, Rocky Mountain Forest and Range Experiment Station at Flagstaff and Coconino National Forest, and the Arizona Game and Fish Department. Statistical analyses of the Beaver Creek and Drake area pellet data mentioned here were by R. H. Smith, Arizona Game and Fish Department.

Juniper-Pinon Type

Juniper-pinon, another of the major types of deer range, yielded an estimated 24 per cent of the statewide deer harvest in 1961. Trees of this type have been uprooted or burned on hundreds of thousands of acres. Much of this was done primarily for livestock range improvement, some was experimental, to determine effects on water yield, and some had the benefitting of deer as one of its objectives. A few of these areas have been sampled in an effort to judge their attractiveness to deer as indicated by deer sign on them, compared with nearby areas on which trees were left standing. Abundance of certain forage plants used by deer was also estimated.

Among four juniper control areas which were studied, early results have ranged from positive to neutral, as far as apparent attractiveness to deer was concerned. Notable factors associated with the different results were livestock grazing and size of the eradication areas.

At one site where deer sign at times suggested a preference of deer for cabled juniper areas, treatment had been on small plots of 120 acres or less, adjacent to larger areas of standing juniper. This was near Grapevine Canyon, southeast of Flagstaff. Livestock did not use these cabled nor standing juniper areas for several years before and after treatment. Native perenniel grasses had increased on the cabled plots, but not on the standing juniper areas, as of three years after cabling. There was no artificial reseeding. On both the cabled and standing juniper areas, there were similar densities of a preferred browse plant, cliffrose *(Cowania mexicana* var. *stansburiana)*; viz., about 67 plants per acre. Significant differences in sample mean pellet densities occurred during the fourth, but not the fifth year after cabling, although mean densities have generally been greater on the cabled areas (TABLE 1).

At three other locations, pellet samples did not strongly imply a preference of deer for uprooted to standing juniper areas, nor vice versa (TABLE I). Juniper control was done on several hundred or a thousand acres or more, and none of the three areas was retired from cattle use. Locations were the Sowats and White Pockets vicinities of the North Kaibab, and an area northwest of Drake.

Stands of preferred browse species were dense at some and sparse at others of the latter three juniper control areas. For example, some of the ridgetop sites of the North Kaibab had more than 500 cliffrose plants per acre. In contrast, at the Drake area, the combined average estimate was fewer than 26 cliffrose and mountain mahogany *(Cercocarpus breviflorus)* plants per acre.

TABLE I. Deer Use of Eradicated and Standing Juniper Areas.

Location	Pellet Groups Per Acre: Areas of Juniper Control		Areas of Standing Juniper	Period of Accumulation	Year of Treatment
Grapevine canyon	166	**	90	Winter 1960-1961	1957
	63	**	23	Summer 1961	
	69		55	Winter 1961-1962	
Sowats	356		385	Winter 1961-1962	1957
White Pockets	124		110	Winter 1961-62	1956
Drake	177		193	Indefinite, to June, 1960	1956

**Mean differences significant at 95% level.
Unstarred mean differences were not significant at 90% level.

Neither the eradicated nor standing juniper areas had cliffrose plants small enough to be seedlings of the current or preceding year, at the time of the browse samples on the North Kaibab and Grapevine areas, four to six years after treatment. In some experimental plantings by the Kaibab National Forest, cliffrose seedlings were destroyed by rabbits. Attempts were made to compare densities of plants slightly larger than seedlings which might represent cliffrose established since pushing or cabling. The sample results were uncertain, since many of the smallest cliffrose plants apparently pre-dated the juniper control work. Evaluation of effects of juniper eradication on cliffrose stand density may require some knowledge of the usual rates of replacement and longevity of cliffrose on various sites. Need for artificial browse planting on given areas could be recommended on the basis of such information.

Cliffrose and other browse species did put forth more new growth on established plants on cleared than on standing juniper areas. This release effect was obvious and common to all juniper control areas. A quantitative appraisal of the difference was attempted for cliffrose in late summer, 1961, on the North Kaibab. 2 Oven-dry weight of current annual growth available to deer was estimated at 5.6 pounds per acre for pushed juniper sites of Sowats and White Pockets, and 2.1 pounds per acre for their standing juniper sites. This source of browse increase should be important to deer where natural stands of preferred shrubs are dense, but it may be no great bonus to expect from juniper control on some of the other ranges.

2. *The United States Forest Service, Kaibab National Forest, assisted with the cliffrose sampling on the North Kaibab.*

The above emphasis on one or two preferred browse species should not suggest that other deer foods be ignored in evaluation of juniper control. A number of plants other than cliffrose contribute much to the support of deer herds in juniper-pinon country. Sagebrush *(Artemisia tridentata)* and juniper, for example, have been eaten in large quantities by deer on the Kaibab and several other western ranges in the juniper type (4, 5, 6, 7, 12, 13, 14). In the present studies, mistletoes *(Phoradendron* and *Arceuthobium, spp.)*, grasses, forbs, and the leaves and berries of junipers were among the items of greater bulk noted in deer rumen samples from the Grapevine Canyon area. Juniper and forbs were some of the major items in Beaver Creek rumen samples.

Chaparral

Some opening up of the extensive stands of broad-leaved evergreen brush is thought desirable for both water and game production. For game, the creation of many small openings is probably the most desirable treatment for chaparral. Costs and other factors may require brush removal on areas somewhat more extensive and less frequent than would be optimum for game. On the Three Bar area, near Roosevelt, studies are being made to determine the extent to which deer may benefit from brush control on a scale feasible for watershed management.

In the Three Bar experiments, herbicides are applied repeatedly on a small watershed of 76 acres, suppressing natural regrowth of shrubs following a wildfire burn (1). Establishment of gress has been encouraged by artificial reseeding with exotic species. Intensity of deer use of this watershed is being compared periodically with that on two nearby watersheds also burned but not treated with herbicides, and with an unburned, untreated area.

During the first two winters following the wildfire and start of treatment, the samples indicated no significant differences in degrees of deer use among the four compared chaparral areas. During the third winter, however, mean density of pellet groups was significantly greater on the herbicide-treated watershed than on any of the other three. At that time, few if any of the shrubs had been killed by the herbicides, although their average crown coverages were about one-third those of the shrubs on the untreated areas. The usual effect of the herbicide was killing back of the shrub crowns, followed by renewed sprouting from the root-crowns each year. Total forb and grass cover on the herbicide-treated watershed was comparable with forb and grass cover on one and greater than that on the other burned but untreated watershed. 3 With one or two exceptions, there were no outstanding differences among the three burned watersheds in the relative abundance of certain herbaceous species preferred by deer. At present, the vegetation treatment is not completed, and it is not known if the difference in degree of deer use will persist.

One concern of wildlife managers has been that non-selective shrub control may reduce the amount of good forage species available for game. Experimentally, repeated burning or herbicide treatments have killed important large browse plants such as holly-leaf buckthorn *(Rhamnus crocea)* (10, 11). In these tests, emphasis has been on shrub live oak *(Quercus turbinella)*, one of the most abundant and most difficult shrubs to kill (8). From the wildlife point of view, complete eradication even of this unpopular species may not be desirable. Although it may be of lower nutrient quality than some other browse species (15), deer do make considerable use of shrub live oak as browse. Further, it is a major source of mast in the chaparral type. At present, it seems unsafe to assume that acorn crops are unimportant to wildlife populations in either the pine-oak type or the chaparral. Fortunately, perhaps, the results to date suggest that complete eradication of shrub live oak is not likely on any large area.

3. *Descriptions of vegetation on the three burned watersheds are based on sample data taken by the United States Forest Service, Rocky Mountain Forest and Range Experiment Station at Tempe.*

The chemicals used against the large shrubs of the chaparral are also detrimental to smaller plants, the half-shrubs and forbs. A number of these are preferred deer foods (TABLE II). Some contribute largely to the support

TABLE II. Some Forbs and Low Shrubs Apparently Preferred by White Tailed or Mule Deer in Central and Southern Arizona.

Agoseris spp.	Ipomoea longifolia
Artemisia ludoviciana	Krameria parvifolia
Calliandra eriophylla	Lotus spp.
Cassia leptadenia	Lupinus blumeri
Delphinium andesicola	Marah gilensis
Dichelostemma pulchellum	("Echinocystis lobata")
Eriastrum spp.	Physalis crassifolia (berries)
Eriogonum spp.	Porophyllum gracile
Erodium cicutarium	Psoralea spp.
Euphorbia melanadenia	Solanum elaeagnifolium (berries)
Gutierrezia spp.	Verbena spp.

References: (3), (9), (16), *and the present studies.*

of deer in certain areas during parts of the year, even though large browse plants are available. Some of these forbs and low shrubs are more typical of native grassland communities than of the chaparral, but often are closely intermixed with the shrub stands. It is planned that the herbicide treatment on the Three Bar watershed will hold the chaparral cover to a low percentage, but will not completely eliminate it. The reduction of competition from large shrubs may allow some of the preferred forbs and half-shrubs eventually to invade or increase, despite their suscejtibility during the herbicide treatments. Such results might more than compensate for the decrease which is planned for the tall browse portion of the deer food supply. These possibilities stimulate the interest of game management in continuing records of the Three Bar watershed experiments.

Mixed Conifer Type

The high-elevation forest of Douglas-fir, spruce, fir, and pine are summer range for some of the State's big game herds. Tests of various watershed management techniques are in progress or in preparation in this forest type in several places in Arizona. The treatments involve different patterns of logging, such as clear-cutting numerous small patches within a watershed, and clearing large areas or entire watersheds.

At the Willow Creek experimental watersheds, south of Alpine, attempts are being made to learn the kinds of food and major subtypes of forest most used by game prior to cutting. The resulting information may be used to recommend modifications in some of the logging methods for benefit of game on the experimental areas, and in other logging operations. Apparent game preferences for some foor species may change, as relative abundance of the plants is altered by logging and its subsequent effects on vegetation. Since the Willow Creek records will cover a period of several years before, as well as after treatment, they may suggest whether the old or possibly new game foods should be encouraged by watershed management practices.

Hunter Use

On the Beaver Creek Experimental Watersheds, there was demonstrated one effect on game which was not a direct result of the vegetation changes. Unusually large numbers of highly mobile hunters came to the area. The roads required by the watershed developments had much to do with this increased attractiveness of the area to hunters, as did the new highway which made it possible to drive from Phoenix to Beaver Creek in three hours or less. During the 1961 deer hunt, the average number of hunters per square mile on the Beaver Creek area was nearly twice that of the larger hunt unit of similar vegetation type which surrounds the Beaver Creek system. Seventy-one per cent of the Beaver Creek hunters were from one metropolitan area, Maricopa County, and 61 per cent spent only one day or less on the Beaver Creek watershed. The kind of hunter use developed there will undoubtedly spread as watershed management extends and intensifies.

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Impact of Watershed Program on Educational Institutions

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Introduction

With its emphasis on research, the Arizona Watershed Program has increased the demand for highly skilled professionals. The many Federal, State, Municipal and private agencies engaged in watershed research and management have increased their demands for hydrologists, foresters, range conservationists, soils men, geologists, engineers, meteorologists, ecologists, fish and wildlife specialists, economists and talented administrators. Many agencies have prepared brochures outlining their needs for college and university graduates of different specialties. These needs have placed increased demands on our educators and educational programs. Besides placing additional responsibilities on existing educational facilities, demands have necessitated the creation of new departments, new courses and provided the opportunities for summer youth programs. For your appreciation, here is a summary of educational facilities and associated research activities that have been expanded to help solve our ever present problem of limited water supplies.

UNIVERSITY OF ARIZONA

Institute of Atmospheric Physics

The Institute of Atmospheric Physics, a research organization established at the University in 1954 with the help of Lewis Douglas, has already made important contributions to this annual symposium. Papers presented by Dr. Kassander and Dr. Battan in 1957 and 1960 covered the possibilities of increasing precipitation by cloud seeding. The use of radar for studying clouds and storms, first introduced by the Institute, is being used more and more by other agencies to study clouds and storm patterns.

Besides research activities of the Institute, staff members provide instruction in meteorology leading to M.S. and Ph.D. degrees. During the past year, one graduate student received national recognition in the Saturday Evening Post for developing a method of desalting sea water. Students graduating in meteorology will undoubtedly extend the horizons of our knowledge in this important phase of watershed management.

Department of Watershed Management.

The Department of Watershed Management was established at the University of Arizona in 1958 with a $120,000 grant from the Charles Lathrop Pack Forestry Foundation. While placing major emphasis on water production, the Department's program of instruction — like our State Watershed Program — recognizes such other multiple resource values as forest products, forage for livestock, wildlife and recreation. Consequently, the watershed management curriculum offers options in hydrology, forest management, forest science and wildland recreation. Also included, are options in range management and range science. Graduate programs leading to M.S. and Ph.D. degrees are available in watershed management, range management and forestry.

Dr. McComb, head of the Department, participated in our 1959 symposium. Professor Rowe made contributions to both the Barr Report in 1956 and to our 1958 symposium, before retiring from the Forest Service to join the Watershed Department Staff. We can look forward to further important contributions from this Department, with 37 graduate students working this year towards their Master and Doctoral degrees in watershed and range management.

Institute for Water Utilization.

The Institute for Water Utilization was established at the University of Arizona in 1954 for the purpose of conducting research in the conservation and utilization of water supplies under semi-arid and arid climates. Research investigations include: developing methods for artificially recharging ground water aquifers; reducing evaporation from stock tanks, reservoirs and lakes; testing materials for paving artificial water catchments; studying water losses by evapo-transpiration and participating in streamflow forecasting. Many of the investigations are being conducted in cooperation with other agencies. Besides research activities, personnel teach courses in watershed hydrology and water utilization.

Sol Resnick, head of the Institute and his associate, George Maddox presented a paper on artificial ground water recharge at last year's watershed symposium.

Department of Agricultural Economics.

The Department of Agricultural Economics has played an important role in the development of the Arizona Watershed Program. The initial starting point for our program was provided by Dr. Barr's report which compiled recommendations of a number of nationally recognized scientists. Dr. Barr's successor, Ray Seltzer, proposed cooperative methods of financing a state-wide watershed program at our second symposium in 1958.

Attracting the interest of the Western Economics Research Council, the Arizona Watershed Program was taken as a case study for the economic analysis of multiple-use in a 1961 meeting held in Tucson.

Under a pending agreement, Dr. Kelso of the University is cooperating with Mr. Worley of the Forest Service in making economic evaluations of the land treatments being applied on the Beaver Creek Project. Also pending, is a research proposal submitted to the Rockefeller Foundation aimed at determining the importance of water to social and economic growth in an arid environment.

With this record, we can expect the Department of Economics to make further contributions to the Watershed Program.

College of Mines.

A year ago, the College of Mines at the University of Arizona announced a new program of instruction in hydrology. To explain this new program, we have with us today Dr. John Harshbarger who participated in our third annual symposium in 1959.

University Library.

Adequate programs of instruction and research require an adequate library. Recognizing this need, the Water Resources Committee suggested the University Library acquire and build-up the strongest possible collection of reference material on water.

University Librarian, Fleming Bennett, reports the "Water Library" now includes approximately 6,000 items. Although the Library has not yet been able to put a bibliographer to work on this project full-time, the acquisition of a good representative collection has moved ahead with the aid of faculty members.

According to Mr. Bennett, the Library is happy to make reference materials available to people interested in water. Except for journals not generally allowed out of the Library, reference material can be mailed for home-use.

ARIZONA STATE UNIVERSITY

Department of Agriculture.

Facets of the Arizona Watershed Program have been included in Agricultural courses taught by Dr. Judd at Arizona State University. Some 50 students regularly enrolled in "The Conservation of Agricultural Resources" and in "Range Management" have had the opportunity of getting first hand information from technical personnel of various Federal, State and private agencies.

Teachers from various parts of the State get acquainted with the Arizona Watershed Program through Dr. Judd's summer workshop in "The Conservation of Natural Resources." As proof these teachers are taking this information back to their classes, our Watershed Division is receiving an ever increasing number of requests from grade and high school students for watershed information.

Department of Civil Engineering.

Through the Civil Engineering Department, headed up by Professor Kersten, courses in hydraulic engineering, hydrology, soil mechanics and water resource development are available to students attending Arizona State University.

Early this year, a seminar on natural resource management was held at Arizona State University for the purpose of calling attention to the need for making the University's talents more readily available to students interested in natural resources. The proceedings of this seminar deserve your special attention.

ARIZONA STATE COLLEGE

Science Department.

Teachers enrolled in Professor Deaver's summer course in "Conservation Education" at Arizona State College get an excellent cross section of conservation activities of Federal, State and private organizations. Our watershed slide show has been regularly scheduled for this course. Through the teachers enrolled in this course, information about our Watershed Program is undoubtedly being transmitted to grade and high school children.

Division of Forestry.

The Division of Forestry was established by the Board of Regents in 1958 at Arizona State College. To tell us more about this new Division, we have with us today, Dr. Charles Minor. Besides giving us an insight into the schedule of courses, the summer field camp, and thinning operations on State Forest lands this past summer, it is hoped that Dr. Minor will highlight some of the important relationships between forest and watershed management.

SCHOOLS OF OTHER STATES

In order to view in proper perspective the facilities of our own schools, we need to keep appraised of educational development in neighboring states. Towards this end, we will have a report today on the Cooperative Watershed Management Unit at Colorado State University, located at Fort Collins. This Watershed Unit was established in 1958 with the assistance of a grant from the Charles Lathrop Pack Forestry Foundation — like our own Watershed Department at the University of Arizona.

As another example of what is happening in other states, the Water Resources Research Institute at Oregon State University was organized to facilitate research on factors affecting the quantity and quality of water available for man's use. Like other water resource programs, the Institute synthesizes the talents of specialists from several University departments.

YOUTH PROGRAMS

The desire of young people to make use of the fine educational facilities of our Universities and Colleges can be instilled at an early age. Several youth programs now underway in Arizona, will undoubtedly encourage young people to pursue careers in natural resource research and management.

Boy Scouts of America

One of the most outstanding conservation programs for Boy Scouts has been developed by Chief Miller and his staff with the aid of a Conservation Committee made up of representatives of several agencies. Guided by the Chief's philosophy of "learning by doing," about one fourth of the 4,000 boys attending Camp Geronimo participate in some phase of conservation. The program has grown considerably since the Chief presented his report at our third symposium. Boys learn the principles of fish and wildlife management, forest management, soil conservation and rodent control under the able guidance of specialists from the State Game and Fish Department, Forest Service, Soil Conservation Service and Federal Fish and Wildlife Service. Scouts attending Camp Geronimo this past summer had a special opportunity to learn about soil and water conservation, geology, surveying and astronomy. Instructors in these fields were provided by the Geological Survey with cooperative financing from the Salt River Project. In their study of water, boys were given an opportunity to make discharge measurements and service water-stage recorders of stream gages installed by the Geological Survey in 1959.

The Explorer Post Program, a program for high school juniors and seniors who have graduated out of scouting, is expanding rapidly under the sponsorship of many business organizations. Formation of Explorer Posts in conservation, is presently being pushed by the Council's Conservation Committee.

Apache Summer Youth Camps.

Tribal Councils of Indian Reservations cooperating with the Bureau of Indian Affairs have established summer youth camps, setting a pattern that could be followed on a State-wide basis. According to reports received from a number of reservations through the Phoenix Office, the youth programs are aimed at providing gainful employment to teenage boys and girls and providing instruction in the conservation of their reservation resources. Although objectives are much the same, methods of financing and operating camps differ between reservations.

On the Fort Apache Indian Reservation, Superintendent Hawley introduced the youth camp idea to the Tribal Council in the spring of 1956. Since 1956, 366 boys have gone through six summer youth camps ranging from 8 to 10 weeks. Work activities have included juniper control, range reseeding, soil and water conservation treatments, improvement of fish habitats, road drainage and maintenance, timber stand improvement and other practices. This 6 year program has been financed with tribal funds totaling $104,000.

Summer camps on the San Carlos Indian Reservation have been in operation the past 4 years. Organized in two 4-week sessions, about 300 boys have participated in such activities as cutting fence posts, clearing juniper and cholla cactus, and cutting oak for charcoal production. For this work, the boys were paid a little more than $11,000. Camp expenses for food, transportation, materials and supervision were financed by donations from a number of sources over and above contributions from the Tribe.

Similar youth camps have been in operation since 1959 on the Unitah and Ouray reservations in Colorado.

Organized for strictly instructional purposes, a Hopi 4-H Conservation Camp held the last week of June in 1961, provided 33 Hopi boys with instruction in conservation and management practices. Indian boys received instruction in soils, sagebrush and juniper control, grass seeding, spring development and gully control.

Cooperative Extension Youth Camps.

The first annual Youth Conservation Camp, made possible by the cooperative efforts of the University Agricultural Extension Service and the Arizona Association of Soil Conservation Districts, was held July 8-14 at Point of Pines. The camp was under the able direction of Barry Freeman and Ray Weick, Watershed Management and 4-H Extension Specialists. Sponsored by $25 scholarships, donated by Soil Conservation Districts, Livestock Associations, Tribal Councils, 4-H Clubs, Future Farmer Chapters and individuals, 43 boys attended the camp from 9 counties. Instruction in the management of timber, range, water, soil, wildlife and recreational resources was provided by personnel from Federal, State, and private organizations.

THE FUTURE

This brief summary has undoubtedly overlooked some phases of the educational program in Arizona as related to natural resources. The possibility of omissions makes the picture even more impressive. New courses of instruction, new research facilities and programs and new youth programs have paralleled the development of the Arizona Watershed Program probably because of the increased demands for highly qualified professionals.

With few exceptions, the mere expansion of existing programs will go a long way towards providing our young people with adequate instruction in natural resource management. While there may be a present need to increase natural resource instruction at grade and high school levels, this will come with time as more and more teachers take advantage of the available resource seminars and courses.

Considerable thought is presently being given the possibility of expanding and developing a conservation work and instruction program for the Industrial School for Boys. It is hoped that we can look forward to the full realization of this possibility within the next year or two.

In summary, the future management and efficient utilization of our water, timber, forage, wildlife and recreation resources will be considerably better than it is today and better than it was in the past. Knowing that future progress will be accomplished by the students of today gives added significance to the teaching profession.

Training In The Field of Water Resources

By
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INTRODUCTION

The growing importance of the development and intelligent management of water supplies for mankind has created an urgent world-wide need for scientifically trained hydrologists. In recent years, many water problems have been amplified by a rise in man's standard of living, the increased production of food and hard-goods, and the habitation of previously undesirable regions. Consequently, water problems are directly related to such things as: 1) An increase in population, 2) a geographic shifting of population centers, 3) a higher demand of water use per capita, 4) deterioration of watersheds and a decrease of perennial water, 5) pollution of streams and lakes by man's wastes, and 6) a shift to semi-arid and arid regions in order to accommodate an increase of agricultural products and provide land space for human occupation.

The water challenge is not limited to desert areas. Actually, intensive development in certain areas has created severe problems where water is plentiful. Supplies adequate in past years have become no longer usable. Man's occupation in certain watersheds has increased the destruction by floods; production of sediment from increased erosion has clogged drainageways; and streams and lakes have been polluted by introduction of wastes from industry and cities. In some areas, inadequate drainage and increased salinity have brought about the loss of arable lands. Many of these problems caused by man cannot be solved by the mere application of money, concrete and labor. Throughout the world, man is confronted with certain knowledge barriers which impede a scientific foundation for the formulation of sound water development plans. As the competition for known water supplies becomes ever more keen, the deficiency in basic knowledge of hydrologic principles becomes progressively much more important. Today he must face the fact that in the resolution of late stage water resources development, he can no longer afford the margin of error which was permissable in the initial stages of water development.

The future achievements of mankind in the field of water resources will depend upon the kind of educational and training programs designed and implemented by colleges and universities. As hydrology is an interdisciplinary science, it requires the talents and skills of a large variety of areas. The water specialist must be well trained in mathematics, physics, chemistry, meteorology, geology, hydromechanics, and agricultural sciences. In addition, he must have a knowledge of economics, social sciences, and law. The training of such persons presents difficult problems to the educational institution attempting to design training programs. Nevertheless, those institutions planning hydrology curricula must exercise creative and broad interdisciplinary programs to meet the future demands.

Importance of research and graduate training cannot be over-stressed as there is much insight to be uncovered on the many hydrologic processes of the water cycle. The attraction of talented students to such rigorous training programs requires substantial financial assistance; otherwise, the objectives cannot be attained. As many nations, experiencing problems in water resources, do not have trained hydrologists nor educational facilities, international and national programs are essential. The production of well-trained hydrologists must be assigned a high priority throughout the world, if man's hopes to obtain optimum benefit of existing water resources are to be fulfilled.

Modern man is confronted with many challenges in order to survive and maintain a high standard of living. It is difficult to judge which might be his greatest challenge at any particular moment of time, as this is a dynamic and exciting world. However, it seems valid to ask, what challenge is greater than the water challenge? It is an unusual day when there are not major news accounts reporting on the destruction of floods, severe effects of drought, water resources development plans, pollution of streams and lakes, litigation disputes over water supplies, needs for additional water, schemes on converting saline water into fresh water, or the immediate demand for action to abate water shortage in local areas. Large amounts of funds are appropriated each year to alleviate many acute problems, and expenditures will continue to climb to allay man's thirst for water.

THE SCIENCE OF HYDROLOGY

The critical importance of water to modern civilization is an adequate reason for the study of hydrology. The benefits derived from the fruits of science for application to the engineering aspects of construction projects are well established. Industry and government have learned that costs of basic research have paid off handsomely in a savings of money, time and effort. The science of hydrology provides a base for sound economic development in addition to the attainment of a realistic understanding of man's hydrologic environment. His ability to accurately describe the physical processes of the many parameters in the water cycle will permit him to master his environment for maximum economic benefit.

There are many concepts and definitions of hydrology, but one that is most suitable for our purpose is taken from **Scientific Hydrology.**[1]

> Hydrology is the science that treats of the waters of the Earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things. The domain of hydrology embraces the full life history of water on the Earth.

R. L. Nace of the U.S. Geological Survey in his discussion of A Plan for International Cooperation in Hydrology 2 states:

> No nation occupies an entire continent. (The subcontinent of Australia is an imperfect exception). No continent has a closed hydrologic system, but each is a part of a global system. Therefore, no nation can learn by itself, within its own boundaries, all that it must know about water and the hydrologic cycle. None can completely learn even its own local water balance within the continental system. On the other hand, no nation can or would send its own scientists to work in the area of other nations. Cooperation among nations is required, so the task is international.

The Training of Hydrologists

Even though many scientists are working in the general area of hydrology, there are very few who claim to be hydrologists. For the most part, they have been educated in diverse fields such as civil engineering, geology, soil science, meteorology, mathematics - physics - chemistry, silvaculture science, and ecology. Most are, in essence, service-trained in that they receive their hydrologic training through apprenticeship or learned their skills by association with particular groups concerned with certain parts of the water cycle; i.e., surface water, ground water, quality of water, agricultural hydrology including irrigation techniques, watershed management, etc. Table 1 shows a distribution of educational background of hydrologists from a sample taken of the American Geophysical Union affiliated in the Section of Hydrology. The data in Table 2 further reveals the lack of depth in graduate training among those practicing hydrology. In contrast to the earth scientists and other scientists, hydrologists are almost wholly lacking in doctoral level training. It is apparent that advanced study is essential if the science of hydrology is to meet its responsibilities and demands.

TABLE 1. Educational background of hydrologists (a

	Percent
Engineering (mainly civil and hydraulic)	55
Geology	28
Meteorology	6
Mathematics, physics, chemistry	6
Other	5

a Adapted from *Scientific Hydrology*, Federal Council for Science and Technology, Table 3, p. 18 (June 1962).

TABLE 2. Level of education of hydrologists and other scientists, 1960 (a

	Hydrologists (percent) 1	Earth scientists (percent)	All scientists (percent)
Less than a bachelor's degree	4	3	3
Bachelor's degree	74	54	37
Master's degree	17	28	25
Doctoral degree	5	15	35

1 Total number of 881 used in computing percentages, includes 70 in hydrography.

a Adapted from *Scientific Hydrology*, Federal Council for Science and Technology, Table 8, p. 19, (June 1962).

In addition, there are some cases where work in hydrology has not been acceptable experience toward membership as a professional engineer. Also, there are organizations which do not have an employment classification as a hydrologist and the technical work is conducted by engineers, foresters, geologists, geographers, soil scientists and others. Consequently, financial rewards and professional advancement has not been as rapid as in established scientific disciplines. In spite of these conditions, there are a number of persons who have, through self-designed training programs and on the job training, equipped themselves to meet the requirements of a scientific hydrologist. Such methods and perseverance are commendable, but today's water problems cannot await the training of top level scientists by such costly and time-consuming methods.

Scope of Hydroolgy Training

Until recent years, it has not been possible for students to obtain coherent training focused on the subject of water. Under the broad definition of hydrology, the science must include training in the understanding of the earth's physical features and in the mechanics of its atmospheric systems. These facts then need to be related to man's social and economic demands for optimum management of water resources. An adequate description of the global water cycle is needed, defining the circulation of water on the earth as a whole. Knowledge on basic hydrologic principles must be increased and disseminated in training programs.

The nucleus of hydrology probably belongs in the realm of earth sciences. The unifying concept is the hydrologic cycle. The cycle begins and ends with the world ocean and involves the transport of water from sea to air, and from air to land. Here it may be stored for long or short periods after which it moves across the land surface in surface streams or through the earth's porous rocks as ground water, and hence back to the sea. During this transitory movement, the water has passed through the gas, liquid, and solid state. It left the sea essentially pure, but during its transit dissolved many inorganic and organic compounds as it passed through one or several biological systems. Further, it has eroded many rocks of diverse types, changed the continental profile, and returns to the sea laden with many minerals and man's wastes.

Measurement of the water budget of oceans and continents and understanding of the dynamics of water vapor in the atmosphere as well as the precipitable water must be evaluated to obtain the net influx of water vapor to areas of water need. It must be recognized that adequate knowledge on the water balance of the globe requires perhaps even greater emphasis than upon the terrestrial phase of the hydrologic cycle.

There still are major gaps in the basic data necessary to adequately explain the distribution of water on the globe. For example, the magnitude of the North African aquifer is not known and as yet no discharge measurements have been made on the Amazon, the world's largest river. There are vast desert, tropical, and artic regions of variable climate for which there are no hydrologic global analyses of the water budget.

Hydrologic Systems

In a global science such as hydrology, it is believed that a systematic approach by a synthesis of the major factors of the lithosphere and atmosphere and their interrelationship provides the best focus on the water cycle. Specific combinations of geologic, geographic, climate and ecologic factors occur in different regions throughout the world and their interrelationship is of major importance. In many areas, the environment has even greater influence on run-off than on precipitation. Unique combinations of environmental factors provide fundamental insight into the behavior of hydrologic systems.

1 Ad Hoc Panel on Hydrology, W.B. Langbein, Chairman, Scientific Hydrology, Federal Council for Science and Technology, (June 1962).

2 A Panel of Hydrologists (U.S.A.), A Proposal and Plan For International Cooperation in Hydrology, Bull. Inter. Assoc. Scien. Hydrol., p. 11 v. 6, (1961).

Although there are several ways for preparing a synthesis of the hydrologic systems and their component processes, the following classification has been suggested by some workers; a) Climatically controlled, such as in tropical, arid and semi-arid, polar, and temperate regions; b) topographically controlled as by mountains, lakes and glaciers; and c) geologically controlled such as by limestone and karst terranes, alluvial basins, stratiform-artesian terranes. In conjunction with numerable hydrologic systems, it is believed that there are components that would prevail to a lesser or greater extent in any one or all systems. An incomplete list of such components might be as follows: a) Evaporation and transpiration, b) soil moisture, c) movement of water in porous media (unsaturated and saturated), d) erosion and sediment transport, rivers and drainage networks, e) storage of water, as in streams, channels, lakes, reservoirs, and in sub-surface rocks. For a complete listing of hydrologic component factors and processes in the earth's water system, the reader is referred to the report prepared by A Panel of Hydrologists. 3

In addition to the physical and biological aspects of hydrology, the student should have certain knowledge of factors that bear on water management. Comparative and quantitative studies of water management techniques, as influenced by land use, water distribution, climatic variability, and economics provide much valuable knowledge. Legal, social and ethnographic characteristics have a large influence on the development of acceptable water projects for mankind. Throughout history, hydrology has been more empirical than theoretical, but the time is now when hydrology must assume its inevitable role as a science.

TRAINING PROGRAMS IN HYDROLOGY

During the last two years, there has been considerable concern and interest among persons in federal and state water resources agencies and in other nations on the shortage of adequately trained manpower. Only a few educational institutions in the United States have enjoyed a long history in offering several basic courses in hydrology, which comprise the formal academic training of today's senior hydrologists. Prior to 1960, less than 60 major universities listed hydrology courses in their catalogs and only 14 of these were offered at a graduate level. In *Scientific Hydrology*, the Ad Hoc Panel 4 reports that as of spring of 1961,

> . . . there are still perhaps only five or six universities which offer anything approaching a program of advanced study in hydrology. For the most part, the institutions offering additional work are located in the west and southwest.

The importance of increasing the number of qualified manpower cannot be overemphasized. The U.S. Senate Select Committee on Water Resources has pointed out the serious deficiencies in the science of hydrology.

On August 7-9, 1962, an Inter-University Conference on Hydrology convened at Lake Arrowhead, sponsored by the Water Resources Center, University of California, Los Angeles. Participants included representatives from nineteen universities and observers from eight federal agencies and the American Geographical Union. The meeting was organized in a response to a need for expanded education and research programs in hydrology at universities in order to discuss the manpower and new knowledge required for present and future water resource developments. Participants were of unanimous opinion that there is a critical shortage of suitably trained manpower in all aspects of hydrology. They firmly believe that universities are obligated to develop adequate educational programs to meet the manpower shortage. The group also agreed that there should be considerable expansion of water research at universities in order to strengthen programs in graduate training.

3 op. cit., p. 22-26 (1961)
4 op. cit., p. 17 (1962).

Courses of Instruction in Hydrology

The current trend in hydrology education is one of expansion by a number of colleges and universities across the nation. A report was compiled by Hackett and Walton 5 from questionnaires completed by 260 institutional departments which includes information on courses offered, textbooks used, degrees granted by institutions, and student training and research programs. Their compilation indicates that 120 departments offered course work in the area of ground water geology and hydrology.

The report lists some 10 colleges and universities which now provide broad coverage in ground-water geology and hydrology. All of these institutions except one are located in the western and southwestern United States. This has certain significance as these areas have experienced population expansion; and the development of adequate water to support these areas presents formidable problems.

During the 1961-62 academic year, some six or seven universities have announced a broader educational program in the field of hydrology. These new programs, for the most part, are interdisciplinary in that several departments have integrated their course offerings for a planned training program. However, in most institutions, the degrees awarded to the student are in the departmental area. One southwestern university offers undergraduate and graduate degrees in Hydrology. An incomplete survey of the course offerings in colleges and universities in the United States is given in Table 3.

TABLE 3. Titles of courses in hydrology and closely related areas offered by educational institutions in the United States.a

PHYSICAL HYDROLOGY

*Hydrology
Groundwater hydrology
*Surface water hydrology
*Field hydrology
*Land mass hydrology
*Watershed hydrology
*Hydrologic systems
*Dynamics of flow systems of the earth
*Quantitative determination of aquifer performance
*Geology of groundwater
*Fluid mechanics
*Hydrodynamics
Flow in porous media
Free surface flow
*Hydraulics of open channels
*Hydraulic engineering
Flood control hydrology
*River hydraulics
Water power engineering
Costal engineering
River-harbor engineering and hydraulics
*Irrigation hydraulics
Drainage of agricultural lands
Seepage and earth dams
*Meteorology
Hydrometeorology
*Physical and dynamical meteorology
*Physical climatology
*Arid zone agroclimatology and micrometeorology
*Physics of soil water
Glacial geology
Permafrost
Fluvial geomorphology
Hydrodynamics of sediment transportation
Limnology
Oceanography
*Water quality and geochemistry
*Quantitative geomorphology
*Analog model analysis of hydrologic systems
*Statistical hydrology
Applied statistics in hydrology
Application of digital computer to hydraulics and sanitary engineering problems

BIOLOGICAL HYDROLOGY	ECO-SOCIO HYDROLOGY
*Forest influences on watershed management	*Water utilization
*Plant-water-soil relationships	*Appraisal and development of water supplies
*Dendrohydrology	Principles of watershed management
Hydrobiology	*Watershed programs, administration and policy
*Water supply and waste water disposal	Wildland hydrology
*Principles of sanitary engineering	*Irrigation management and water conservation
Water pollution control	Water institutions and economic
Chesistry of water purification and sewage treatment	Economics of water resources
Atmospheric pollution	*Water law
*Industrial wastes	Human ecology
Disposal of radio-active wastes	*Land economics

a These courses have been grouped into three major divisions, such as Physical, Biological and Eco-Socio Hydrology.
*Courses offered in hydrology programs at the University of Arizona, Tucson.

Most of the newly announced programs are designed for graduate training in hydrology. The basic requirement for entrance to these programs leans heavily on substantial background in mathematics, physics, chemistry, geology, and hydro-mechanics. The programs differ somewhat in concentration of subject matter dependent upon the area in which the advanced degree is awarded. New techniques in statistics, operations research, and systems engineering are some of the new tools being incorporated in modern programs. Adequate training in hydrology must obtain much assistance from the allied disciplines.

Current enrollment of students entering these new programs is not available; however, many students have been seeking such inter-disciplinary training programs in water resources. A large percentage of the students are from other nations seeking competent training in the water field. A large percentage of the foreign students is from the Middle East and Eastern countries. These nations have a great need for well-trained persons in hydrology to provide the necessary self competence in their water resources development. There is hope that the newly developing countries will avoid repetition of the errors made by those countries which are now more highly developed. Consequently, students receiving their training in present-day educational programs will prove to be an important asset in planning new water development projects.

Hydrology Training at the University of Arizona

The University of Arizona, in the fall of 1961, initiated a new program in scientific hydrology which provides broad training in fundamentals and a rigorous synthesis of hydrologic systems. This program includes undergraduate and graduate curricula leading to the degree of Bachelor of Science, Master of Science, and Doctor of Philosophy in Hydrology. The curriculum includes basic courses in mathematics, physics, chemistry, geology, meteorology, hydromechanics, botany, economics, and social sciences. In addition, eight completely new hydrology courses have been designed to deal with scientific principles and systems analyses of the many hydrologic interrelationships at the graduate level.

The hydrology program is guided by a committee composed of one representative from each of the essential departments. The committee, acting in lieu of a departmental faculty, recommends acceptance or denial of applications, advises students, develops and approves graduate study programs, approves research directors (who may or may not be committee members), and suggests examining committees.

The graduate program affords opportunities for graduate study to students holding degrees in other fields such as civil engineering, geology, soils, meteorology, and agriculture. Credit in all of the undergraduate hydrology courses is not required provided students fulfill certain requirements as follows: Differential equations, general chemistry and physics, physical and historical geology, fluid mechanics, botany or biology, economics, engineering drawing and data analysis, field techniques, surveying and geologic mapping. Promising applicants deficient in several of these areas may be admitted with the understanding that background courses in the required subjects must be taken without graduate credit.

Areas of Broad Training

The University of Arizona has achieved a recognized position in the field of arid land studies and water problems, which is to be expected, as it is located in the arid southwest. Some of the problems relating directly or indirectly to water are unique. The emphasis on teaching and research in hydrology naturally varies greatly from department to department. The exceptional scope of the University's work in this and closely related fields is indicated by the diversity of activities outlined as follows:

The Institute of Atmospheric Physics is a research organization with the primary objective of gaining basic knowledge of the weather and climate of Arizona, of the southwest, and of arid regions in general. The Institute is attacking the problem of water as the most fundamental factor in an arid land, all the way from the standpoint of the regional relationships of the flux of water vapor down to and including the microphysical properties of the liquid and solid water particles in the clouds. Particular emphasis is placed upon the study of those atmospheric processes which are associated with the formation of clouds and rain. The Institute hopes, through its research, to serve the interests of all those who struggle with the water problems of the arid zones of the earth.

A great many studies relating to water have been completed, or are in progress, or planned in the various departments of the College of Agriculture. The Agricultural Experiment Station cooperates actively with various government organizations on water matters. Material of exceptional hydrologic significance has been assembled over a period of many years by the Department of Agricultural Engineering. This department possesses one of the most complete historical records of a ground water basin ever assembled. Closely related to this work is the effort to determine transmissibility and specific yield of water-bearing formations in these valleys.

The Institute of Water Utilization is involved in fundamental and applied research relating chiefly to the development, conservation and utilization of water resources under semi-arid and arid climatic conditions. A major subject of research is in the area of artificial recharge, related to the ground water supply in Arizona. The Department of Watershed Management is primarily concerned with the development of managerial methods which will allow wildland watersheds to produce optimum yields of water and other products coincident with satisfactory flood and erosion control. In connection with this goal, investigations of transpiration rates of various plants in the wildland watersheds are being carried out with the aim of manipulating vegetation for maximum water yield.

5 Hackett, James N. and William C. Walton, Educational and Academic Research Facilities in Ground-Water Geology and Hydrology in the United States and Canada, Research Committee, Technical Division of the National Water Well Association, mimeographed, (May 1961).

Problems of soil water and water quality are the special concern of the Department of Agricultural Chemistry and Soils. For more than 45 years, the testing laboratory of this department has been analyzing water samples sent in from widely scattered areas. Records have been retained from thousands of chemical analyses of water samples. The department is also conducting research into a variety of problems concerned with the movement of water and nutrients through soil and into plants.

The Department of Agricultural Economics is investigating such matters as the pricing of water, the patterns of watershed development and use, structures of water law, and water regulatory organization.

The interests of the department of Civil Engineering lie in the area of water resources development and in the conception, design, construction and operation of water resources development projects. Recent and current research includes a study of the hydraulics of long culverts and the hydraulics of partially full flow in conduits of various shapes.

The Geochronology Laboratories form an interdisciplinary unit which studies various problems, some of them relating to the occurrence and movements of water during the earth's geologic history. They draw upon geologists, geophysicists, geochemists, botanists, atmospheric physicists and others to help solve these problems.

The Laboratory of Tree-Ring Research is one of the important supporting units for the hydrology program. It is presently stressing studies on the relation between environmental parameters and the radial growth of trees. This research is directly related to hydrology in that stream flow is determined by some of the same parameters. There are strong indications that variations in width of tree-rings may be used as a measure of the variations in precipitation and streamflow during the past 5,000 years.

CONCLUSIONS

The shortage of trained manpower to work on the many complex water problems throughout the world is a major concern of many educators. The learning processes in hydrology education must be undertaken by the college and university equipped to provide scientific training in hydrology. The immediate need for professional hydrologists adds to the importance of establishing graduate programs in hydrology. In conjunction with graduate training, research studies must be developed to go beyond problems undertaken by graduate students. Indeed, the lack of scientific knowledge of hydrologic phenomena can be related to the past deficiency of scientific curiosity and motivation of basic research in hydrology.

Educational institutions in the United States have accepted the importance of the water challenge and now offer well-designed curricula for training in scientific hydrology. There are about 20 colleges and universities throughout the nation which are now focusing expanded course offerings on the field of water resources. Most of these institutions are land-grant or state universities in the western and southwestern states, the others are scattered throughout the midwest and the eastern cotsal areas of the United States. There is a common opinion among hydrology educators that comprehensive programs must be developed to elevate hydrology into a scientific discipline parallel to other physical sciences. The recent intense interest and effort being placed on the inter-university cooperation for the training of professional and scientific workers in the field of water resources probably marks the embarkation of a new era of educational development.

As hydrology is a global science, it provides an intellectual medium for international exchange of ideas and knowledge on man's greatest resource — water. The total impact of the new trend in training programs will undoubtedly become evident in the better solution of water problems throughout the world. Such solutions will take place in the highly developed as well as the newly developing countries. The time has arrived when man can look forward to receiving additional benefits from highly effective management of the world's water supply.

The Watershed Management Program At Colorado State University

ROBERT E. DILS 1
and
BERNARD FRANK 2

New and ever-increasing requirements for water are focusing urgent attention on the need for trained scientists in various aspects of water resources development, improvement and management. How new this field is, is indicated by the fact that most hydrologists and watershed specialists are still either self-made or have adapted themselves from related professions by in-service training and experience. Only within the past few years have universities begun to offer degree programs in watershed management or hydrology.

In recognition of the need for more adequate training in watershed management, the Charles Lathrop Pack Forestry Foundation through Dr. Arthur N. Pack, made grants in 1958 to the Universities of Arizona and New Mexico and to Colorado State University for the express purpose of furthering education in this vital and complex field.

So far as Colorado State University is concerned, this grant made possible the establishment of a Cooperative Watershed Management Unit within the College of Forestry and Range Management. With the assistance of an advisory committee composed of faculty and public agency personnel, an undergraduate curriculum leading to a B.S. degree with major in watershed management was conceived and approved by the University. The curriculum follows closely the recommendations of the Society of American Foresters' Committee on the Training of Men in Forest Hydrology and Watershed Management. 3)

The complexity of the water resource and especially the wide variety of techniques and practices, its improvement and management requirements, make essential a multidisciplined approach to an understanding of its behavior and control. Consequently, major emphasis in the program has been placed on graduate training. Programs leading to the M.S. and Ph.D. degrees in watershed management have therefore been approved by our University.

In further recognition of the need for specialized professional training in this field, the U.S. Forest Service authorized the appointment of a watershed research scientist to cooperate with our Unit in its graduate program. On recommendation of Director Raymond Price, Mr. Bertram C. Goodell of the Rocky Mountain Forest and Range Experiment Station was assigned to the post of Research Professor of Watershed Management. In addition to conducting independent studies, Bert Goodell assists and guides graduate students in the selection and conduct of their thesis or dissertation research.

1) Charles Lathrop Pack Professor of Watershed Management and Leader, Cooperative Watershed Management Unit, College of Forestry and Range Management, Colorado State University.

2) Professor of Watershed Management, Colorado State University.

Professional coursework offered at both the undergraduate and graduate student levels includes the principles of watershed management, largely a basic course in forest influences and watershed hydrology; watershed management techniques, a course which involves field and laboratory work as well as tours to observe and analyze management and rehabilitation activities on public and private forest, range and farm lands; and watershed programs, administration and policy, a course which covers such items as the history of water conservation, federal, state and local responsibilities in water resources protection, development and allocation, and the basic principles of water law.

Students in other disciplines, particularly forest management and range management, are encouraged to elect these courses in their programs since they will be conducting or participating in much of the watershed management activity of the future.

Graduate courses include watershed analysis, in which the student participates in a field survey of a local watershed and collaborates with his fellows in the preparation of a thorough-going resource survey report and problem analysis, and recommended land and water management practices and remedial measures; research methods in watershed management, involving an evaluation of scientific methods and techniques as well as critical reviews of the results of significant research; and advanced studies in the hydrology and hydrologic characteristics of wildlands. We hope also to add a graduate course in snow physics and snow hydrology in the near future.

In addition to the above more or less standardized courses, there are available courses on special problems, seminars and individual research.

The nature and interrelationships of the water resource are such that most of the work required in our program is necessarily undertaken in related fields. Since there is as yet no Civil Service classification of watershed manager or hydrologist, undergraduate students who wish to enter federal service must take sufficient work in forestry or range management to meet Civil Service requirements for forester or range conservationist. Additional courses in water resource areas includes fluid mechanics, hydrology, meteorology, soil physics, geomorphology and land economics. Prerequisites to some of these requirements are mathematics through calculus, statistics, statics, dynamics, and at least a year each in chemistry and physics. Further study is required in the biological sciences and humanities.

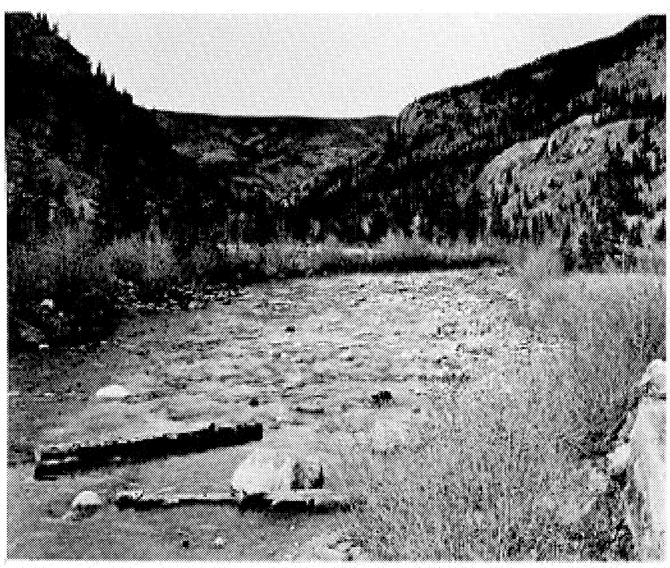
3) Wilm, H. G., et al, 1957. The Training of Men in Forest Hydrology and Watershed Management. Jour. For. 55 (4: 268-272.

Graduate programs are tailored to the individual student and depend primarily upon his academic and work experience, personal interests and the research he elects to meet his graduate degree requirements. Our graduate students to date have had previous training in forestry, range management, civil or sanitary engineering, meteorology, physics and soil science. However, all must develop and demonstrate an understanding of the ecological and biological sciences as well as the hydrology that are so fundamental to a thorough understanding and application of watershed management principles.

Financial assistance to attract top-quality graduate students is at least as essential as it is to attract a good college athlete. Since 1958 our graduates have been awarded or have won through national competition 10 Charles Lathrop Pack graduate research assistantships, 6 National Defense graduate fellowships, 4 cooperative National Science Foundation graduate fellowships, 2 Crown Zellerbach Foundation graduate fellowships, and 1 fellowship each from the Boettcher Foundation, American-Swiss Foundation and the Fulbright program. Also during the coming academic year one student will be financed by a Colorado State University Economics Department research assistantship and another through a graduate research assistantship financed by the Colorado Game and Fish Department.

Graduate student theses have covered a wide variety of subjects ranging from forest stand indicators of solar radiation, characteristics and causes of soil piping erosion, snow accumulation and melting, and watershed hydrology to the economics of jointly managing land areas for timber and water.

Field and laboratory facilities for water research at Colorado State University are outstanding. Within 40 miles of the campus we have access to five major life zones ranging from the Great Plains to alpine tundra and snowfields. Four major United States rivers originate in Colorado's mountains: the Platte, Arkansas, Rio Grande and Colorado — all within a half-day's drive from Fort Collins. Outstanding scientists and technicians in soil and water conservation, hydrology and watershed management in the U.S. Forest Service, Agricultural Research Service, Soil Conservation Service, Geological Survey, Bureau of Reclamation, Public Health Service and the Boulder Colorado Laboratories of the National Bureau of Standards, as well as state agencies concerned with water resources are located on or near our campus and are available for guest lectures, seminars and consultation. The facilities of the Rocky Mountain Station's Fraser and Manitou Experimental Forests near Denver are readily accessible for instructional and research purposes. When practical, summer employment is provided by federal and state agencies to both undergraduate and graduate students, thus providing valuable experience and often excellent research opportunity.



The Cache la Poudre River west of Fort Collins provides an excellent outdoor laboratory for instruction and research in watershed mnagement.

Students receive practical experience in measuring streamflow.

University facilities include a new hydraulics laboratory, which will have a separate hydrobiology laboratory, wind tunnels, a low - power nuclear reactor, and environment-controlled growth chambers as well as greenhouse space. A small research laboratory is being developed within the boundaries of the Roosevelt National Forest at Pingree Park, site of the University's Summer Camp at 9,000 feet elevation. The watershed of the Little South Fork of the Cache la Poudre River, a major tributary of the South Platte, is being developed for demonstration and research purposes. Four gaging stations are now being maintained by the U.S. Geological Survey in cooperation with the Colorado Water Conservation Board and the University. Weather stations and snow surveys are currently conducted or maintained by University students and staff.

To date six students have qualified for the B.S. degree in watershed management. Four of these are now pursuing graduate programs in this field. The other two are employed by the U.S. Forest Service, one in national forest administration, and one in research. One of the graduates is currently in Australia studying watershed management on a Fulbright graduate fellowship.

Of six students who have completed the M.S. Degree, three are employed by the Rocky Mountain Forest and Range Experiment Station, two are completing military service requirements and one is with the California Department of Water Resources. Four more students have completed our doctorate program. Two of these are now in university teaching, one is entering the Army and one is currently studying microclimatology at the University of Munich in Germany on a NATO post-doctoral fellowship.

The anticipated enrollment this fall is 20 to 25 undergraduates and 25 graduate students. Of the graduate students 11 are candidates for the Ph.D degree and 4 are non-degree students. Foreign nationals represent Austria, Switzerland, Iraq, India, Turkey, Ghana and Taiwan.

National and international interest in training scientists and technicians in hydrology, water resources and watershed management has led to the establishment of several new educational programs within the past few years. Colorado State University has recently initiated offerings in hydrology in the Civil Engineering Department and in hydrogeology in its Geology Department. Similarly, as many of you know, the University of Arizona conducts a program in watershed management which also received its initial impetus through a grant from the Charles Lathrop Pack Forestry Foundation. That University likewise has programs in hydraulics and water research in its Engineering College and Agricultural Experiment Station and recently initiated a new curriculum in hydrology in its School of Mines.

All these activities in the Rocky Mountain region, together with new programs at other institutions should go far to strengthen our knowledge and competence in hydrology, watershed management and the water resources field as a whole and to furnish the trained manpower so essential to meeting tomorrow's challenges for water conservation and more and better water supplies.

Forest Management at Arizona State College

By CHARLES O. MINOR
Director Division Of Forestry

The Division of Forestry at Arizona State College, now beginning its fifth year, offers the only professional forestry training in the Arizona—New Mexico area. The four year program leads to the degree of Bachelor of Science in Forestry. While registration is not yet completed, approximately 140 students are enrolled this Fall. The division has its own building with some 22,000 square feet of office, classroom, and laboratory space, and has a present faculty of six.

The division is primarily charged with teaching—our objective is to develop the student as a man, a citizen, and a professional forester. He must have a foundation of basic sciences, must develop an understanding of human relations and cultures, and must attain technical proficiency in forestry. In our program the first two years are devoted to a background in English, science, and mathematics, together with surveying, economics, public speaking, and technical writing. Following the sophomore year students enroll in an eight-week summer field program. Eight or more hours per day, five days per week, are spent in the field actually doing the field jobs of forest management. The upperclass, or professional years are spent in technical forestry courses, in electives from the social sciences and humanities, and in acquiring a degree of specialization in some field of forestry. Throughout the program emphasis is on multiple-use management — every subject is considered from the aspect of the total forest resource. If in a field lab students carry out a particular operation, questions are immediately posed regarding the effect upon timber, grass, water, game, and recreation.

FIGURE 1. Pre-commercial thinning of Ponderosa pine on Arizona State College school forest.

FIGURE 2. Preparing site for tree planting on school forest.

Laboratory experience is an essential part of forestry education and we are especially fortunate in that Arizona State College is ideally located for the study of forestry. Flagstaff is in the heart of the largest ponderosa pine forest in America. Fifteen miles from the campus, at Fort Valley, is the oldest experimental forest in the United States. Throughout northern Arizona are modern sawmills; the Nagel plant at Winslow and the Navajo mill just dedicated, are two new modern mills incorporating the latest in sawmill design. The construction of the new modern pulp mill at Snowflake opens a whole new era of intensity in forest management and utilization. At Prescott are a wood preservation plant and a cabin-log plant. Close at hand are famous national monuments, parks, and recreational areas. The Beaver Creek watershed area, mentioned so many times at these Symposiums, is within easy driving distance. All of these facilities are used extensively as a basic part of the forestry program.

Most of the field work, both in the summer and in afternoon labs during the academic year, is carried out on the Arizona State College School Forest. This area, comprised of 4,000 acres of state land used under cooperative agreement with the State Land Department, is within five miles of the campus. The area is used on an average of four afternoons per week Fall and Spring. The school forest also serves as a research and demonstration area. Studies are being conducted on thinning intensity in ponderosa pine (sapling and pole size stands), planting, direct seeding, forest and range inventory methods, and soil moisture relations. Also under study are forest insect and disease problems, and an investigation of porcupine damage to ponderosa pine. The Division of Forestry hopes to assist in the development of forest management in Arizona by demonstrating and encouraging proper care and use of all forest resources.

Activities carried out on the School Forest are intended as practical student exercises and also to serve as usable examples for the foresters and forest landowners of the state. As an example, during the past summer, sixty acres of sapling-size pine were thinned, using student labor, under provisions of Practice B-10 of the Agricultural Conservation Program. Included in the treated area were stands with as many as 7,000 stems per acre. After thinning these were reduced to 400 trees per acre. Increases in tree growth, forage, and water will be carefully studied.

The forestry school is also engaged in various cooperative research projects with federal and private forestry agencies. Close realtions are maintained with the Flagstaff Research Center, Rocky Mountain Forest and Range Experiment Station and with local private companies. From such cooperative studies have come some eight publications in the past three years. One major study, on forest growth potential, should be completed during the coming year.

We feel we have come a long way in the four years since the forestry school was established. However, the real test of our success will lie in our graduates and their performance. To date, we are receiving very satisfactory reports from employers regarding our first graduates. Perhaps if from nothing else, this is because our students are made to feel that they have a greater than average responsibility. After all, they are learning to manage the resources upon which may hinge the future of Arizona and of the nation.